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COMPARISON OF THREE COMBAT LOGISTIC   FORCE
MODELS

by

Sinclair M. Harris

March 1989

Thesis Advisor: Wayne P. Hughes

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Comparison of Three
Combat Logistic Force Models

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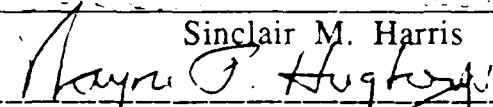
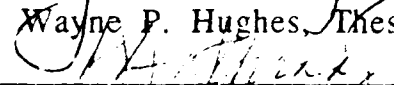MASTER OF SCIENCE IN OPERATIONS RESEARCH

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ABSTRACT

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Analysis showed that RASM and BFORM results were very similar. However, BFORM results tended to be less optimistic than RASM. RASM and BFORM shared many common strengths and weaknesses. Most notable of the models' strengths was the flexibility that the user had in defining the scenario. Significant weaknesses in the models included assumptions of no attrition and unrealistic scheduling of CLF assets. RSRG/SOS did not compare well with the other models because of its aggregated modelling design.

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I. INTRODUCTION

A. BACKGROUND

Only a few models that describe the logistical processes of a naval battle group have been developed. These models have been used to answer questions such as, "What effect will the limited number of support ships and their characteristics have on a battle force mission?" And, if the effect is notable; "How many support ships will be needed to sustain the battle force?" Recent congressional reports state that the proposed shipbuilding plans of the past administration call for an insufficient number of support ships to be built to meet even the Navy's most modest estimate [Ref. 1: p. 19]. The results obtained by these models have influenced the conclusions made by program analysts on what best supports the Navy's needs.

Logistical considerations are difficult to predict at the CINC, service force,or battle group staff level. Some relatively simple facets of the effect that logistics has on an operation have been ignored because they render the operation too difficult to complete or they don't relate to the force's war fighting ability. The avoidance of logistic issues can give tacticians a false sense of confidence in their ability to successfully conduct an operation. The distance between the areas of battle force operation and Advanced Logistic Support Bases (ASLBs) has widened, as the Navy slowly has moved out of overseas bases around the world. This distance has put a strain on the ability of a battle force to conduct sustained operations, since the logistical pipeline has also grown in length. Planning for battle force operations will require much more logistical foresight and careful utilization of logistic assets. A well designed model of battle force logistical operations is an inexpensive method of estimating the impact of logistic ships and their capabilities on tactical

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situations. Logistic models can assist the battle group staff in the mission planning and evaluation.

Each of the recently developed logistic models examined has attempted to measure logistical parameters in a battle force setting. The questions which arise are, *"Is there any difference between these models?"* And, *"Are there problems in the way that these models perform their analysis of logistical support of the battle force?"*

The purpose of this thesis is to compare three battle force replenishment models: Battle Force Operations Replenishment Model(BFORM), Resupply Sealift Requirements Generator & Ship On-Line Scheduler(RSRG/SOS) and Replenishment at Sea Model(RASM). By using a variety of measures of effectiveness (MOEs), this study will evaluate how Combat Logistic Force (CLF) support affects the battle group's war fighting capability.

The Combat Logistic Force (CLF) is composed of ammunition ships, oilers and stores ships which are used to support the Navy's maritime strategy in battle force operations. The scope of this thesis is limited to the station ship operations primarily, and to a lesser extent, shuttle ships. A station ship refers to a vessel which is assigned to a battle group for the purpose of distributing a variety of combat essential commodities. For example, oilers (AOs), ammunition ships (AEs), and fast combat multi-product support ships (AOEs and AORs). Shuttle ships also distribute their vital commodities to battle force units, but their primary purpose is to resupply the station ships of a battle force with goods obtained at the Advanced Logistic Support Base (ALSBs). These ships will typically be of the oiler (T-AO) and ammunition ship (T-AE) variety.

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B. OVERVIEW

This thesis will use various MOEs to compare three battle force logistic models. The emphasis in this will be how these models compare in supporting the analyst (fleet planner or program appraisal analyst) in evaluating the effect of logistic operations on the battle force.

All too often a model is assumed to be good for any situation, while in reality it is mostly dependent on the artificialities of the scenario in which it is presented. In this thesis, several fictitious scenarios were developed in an attempt to span representative battle force situations without violating the unclassified nature of this thesis. A brief description of the three models (BFORM, RASM, and RSRG/SOS) used in this analysis will also be included in this thesis. A relative comparison of model results in similar scenarios will be presented. In the final section, conclusions on the usefulness of these three models, and areas that need further study in the area logistical model building will be discussed.

II. DESCRIPTIONS OF MODELS

The following is a brief summary of the three models analyzed in this thesis. The information used in writing this summary comes mostly from the user manuals provided by the model developers. However, this author had to contact the programmers for clarification on many of the mathematical assumptions and program coding that were not clearly explained in the user manuals. Of the three models that are discussed, only the Replenishment-At-Sea Model (RASM) provided an additional manual covering the mathematics of the model [Ref. 2:p. 3].

A. BATTLE FORCE OPERATION REPLENISHMENT MODEL (BFORM)

1. Background

BFORM was developed in 1988 at Johns Hopkins University Applied Physics Laboratory's Naval Warfare Analysis Department under tasking from the Chief of Naval Operations, Program Resource Appraisal Division (OP-81), to provide the Navy analyst with a microcomputer-based model for evaluating the consequences of different choices in CLF ship design, strategy and mix in a given tactical scenario for a user-defined battle group [Ref. 3:p. 4]. The model is written in Pascal and can be run on the IBM PC (or IBM compatible systems). BFORM is a deterministic model with most of the variables available for user manipulation. Changes to these variables are made by menu driven selection so that the user does not require any programming skills in order to run the model. Several measures are provided as standard output, to either printer or screen, for scenario analysis.

BFORM allows user input for a great number of variables. Control variables such as the number of ships (CLF and combatant) in each task group, fuel and ordnance consumption and transfer rate, and relative priority of each type of

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combatant are available for the analyst to modify. A complete list of these variables are presented in Table 2.3 (see page 30). This flexibility greatly enhances the number of different types of scenarios that can be modelled using BFORM.

2. Assumptions

BFORM makes various simplifying assumptions in order to make the model easy to operate as well as not to over estimate the capability of the CLF ships to sustain the battle force. In some cases, however, there are instances where modelers leaned more toward simplicity than detail. For example, none of the CLF ships burn their own fuel during a run. This causes the amount of fuel available for transfer to other ships in the battle force to be artificially high. Other major assumptions are as follows:

a) The battle force moves in same course from start to finish of a simulation run.

b) All ships proceed at Speed of Advance(SOA), or maximum speed, except when underway replenishment is being conducted.

c) Reliability of unrep equipment and operator proficiency does not change during run.

d) Changes in the relative position of ships are due only to unrep events.

e) CLF ships only expend fuel when transferring and do not use any of their own fuel during the run.

f) Screen ships travel at flank speed when returning to their patrol areas[1], even if their stations are directly behind them.

h) All commodities are assumed to be transferred simultaneously. The transfer time for a particular unrep event is the maximum of the time calculated to transfer ordnance or fuel.

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[1] patrol area is a user defined sector in the formation that the screen ship can stay in without being off station.

i) Ordnance transfer is sequential; therefore, the total unrep time is the sum of each type of ordnance that is replenished.

j) Fuel transfer is assumed to be completed at an even rate with no pressurizing or back pressurizing required. In reality, fueling ships typically will slowly build up to full pressure, maintain an average pressure, and then drop their fuelling hose pressures near the end of a transfer.

k) Stores transfer time is assumed to be less than either fuel or ordnance, and therefore not considered in this logistic model. The model was modified by the author to keep track of stores in order to evaluate the logistic models on a more even basis.

l) The battle force composition remains constant throughout the run.

3. Kinematics

BFORM allows the user to choose between three different modes of operation for the battle force CLF ships. These modes are discussed below.

a. Delivery Boy Mode

In this replenishment scheme, CLF ships will travel to the receiving ships to deliver requested commodities. Closing time plus twenty minutes (for coming alongside, rigging, etc.) is considered as the time used by the ships prior to unrep commencement. During unrep, the two ships will travel at unrep speed and thus force the receiving ship out of its home position. Upon completion, the receiving ship will travel at flank speed back to its home position. The replenishment ship will look to the scheduling algorithm to determine the next ship to be replenished. The scheduler looks at all the ships in the formation not already involved in unrep in order to determine the level of each commodity. The commodity level is expressed as the ratio of absolute level to the absolute capacity. If a commodity level is greater than the upper threshold (user defined variable), then it is assigned a value greater than one so that it is not considered for possible unrep. Each of the remaining ships is then assigned a priority number(P_i) based on the weighted average of the user defined priority values. The product of the normalized ship class priority(c_{ij}) and the normalized commodity priority(w_{ij})

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(two more user defined variables) is used in this calculation (see Figure 2.1) [Ref. 3:p. 5]. The priority number is then multiplied by the ship's distance from the station ship normalized by the distance of the furthest ship considered for replenishment. The ship with the lowest priority is then selected for a replenishment. The scheduling station ship will perform the replenishment unless there is another free station (not involved in replenishment) ship closer to the selected ship. The only exception to this system occurs when a ship has any single commodity level below its lower threshold (user defined); the scheduler will send the closest available free station ship there first.

i = ship reference

j = commodity reference

sss = scheduling station ship

cl_{ij} = relative level of commodity "j" on ship "i"

ut_{ij} = upper threshold of commodity "j" on ship "i"

lt_{ij} = lower threshold of commodity "j" on ship "i"

$d_{i,sss}$ = distance from ship "i" to "sss"

d_{max} = maximum distance to "sss" from any ship "i"

$$w_{ij} = \left[\left(\frac{commodity}{priority_j} \right) \left(\frac{ship\ class}{priority_i} \right) \right]^{-1}$$

$$P_i = \left(\sum_j w_{ij}\ cl_{ij} \right) \frac{Min}{j} \left(w_{ij}\ cl_{ij} \right) \frac{d_{i,sss}}{d_{max}}$$

Figure 2.1 SCHEDULING ALGORITHM

b. Service (Gas) Station Mode

Receiving ships travel to the station ship's assigned position in the battle force. Once replenishment begins, both receiving ships and station ship proceed at unrep speed. Upon completion of replenishment, the vessels will return to their assigned positions at flank speed. In this mode, a station ship can schedule up to two receiving ships for simultaneous replenishment. The scheduling for the first ship is done in the same manner as in the Delivery Boy Priority Scheme. The second ship is then assumed to be the ship closest to the station ship's current replenishment operation location. The second ship will remain in the priority list and must reach the station ship within 20 minutes of the beginning of the station ship's first replenishment. If the second ship cannot fulfill this criteria or if there is no second ship, then the replenishment proceeds with the first ship only. In the Service (Gas) Station mode, station ships will attempt to schedule a replenishment to occur at their operation locations as soon as they are free. If they are not successful, they will attempt to schedule an replenishment when they return to their operating stations at half hour intervals.

c. Moving Service (Gas) Station

In the Moving Service (Gas) Station mode, there are two scheduling algorithms. The first is an algorithm to select an operation area (phantom ship). Once the station ship is in the operating area, it must then schedule the individual ships for replenishments. When a station ship can no longer schedule an individual ship in an area, it will attempt to find a new area. If it cannot, it will remain in the old area, steaming at the SOA and attempting to find a new area at half hour intervals. The operating area for a station ship is selected by first determining the

highest priority ship in each phantom ship[2] operation area using the previously described scheduling algorithm. Once a station ship is in an area, the ship scheduling is done in the same manner as in the regular Service (Gas) Station mode except that no ships will be scheduled from outside of the phantom ship area. Thus, if the user does not plan the phantom ships to provide coverage of all ships, some will not be scheduled for replenishment.

d. Shuttle Ship Scheduling

Shuttle ships operate as normal station ships from the time that they are activated until the point that they leave the formation. The exception occurs in their need to replenish station ships. While station ships cannot unrep other station ships, shuttle ships can. Scheduling is done in the same manner as any other ship except that the station ships are scheduled only when they are unable to schedule another ship themselves. In the Moving Service (Gas) Station mode, two station ships are not normally allowed to be in the same operation area at the same time. In order to allow a shuttle ship to replenish a station ship, shuttle ships may be scheduled to be in an operation area that already contains a station ship or a shuttle ship. Operations such as these are defined as station ship console events.

In the event that a shuttle ship is sent to the formation as a console ship, it will schedule replenishment as in the Delivery Boy mode; however, it will only search for station ships independent of their locations. Hence, all station ships will be considered, and the priority number will not be multiplied by the normalized distance from the console ship. In addition, if any station ships are in critical need of replenishment, the one which is in greatest need of any commodity will be

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[2]A phantom ship is the point designated by the user as a replenishment destination. This position is normally midway between the center of the formation and outer screen ships.

chosen. Once a station ship is chosen, the console ship goes to the station ship to perform replenishment, as in the Delivery Boy mode.

e. Weather

Weather has two effects on the BFORM. As weather degrades, the direction of movement of ships involved in an unrep moves away from the battle group PIM (plan of intended movement). Therefore, as weather worsens, ships will fall further behind the battle group as the replenishment proceeds. The second effect is the reduction in transfer rate. Sea states from 1 to 3 have no effect on transfer rate. A sea state of 4 results in a one third reduction in transfer rate. At sea states 5 and above, no replenishments will be scheduled. Unreps previously scheduled, but not yet started will proceed at one-third of the normal rate. Weather events are scheduled by the user and stay in effect until changed by the user. Model programmers realized the sensitivity of replenishment performance to the environment; however, no reliable information exists on when to implement the reduction.

4. Fuel Usage

The user is able to enter the fuel usage of ships from fourteen to thirty two knots. The minimum and maximum rates are used when the ship is moving at or below 13, and at 32 knots or above. A ship's fuel usage is in gallons and is rounded off to whole gallons. This is different from what is done in RASM or RSRG/SOS, but only accounts for a small amount of the difference in model results in the area of fuel consumption. Aviation fuel usage is measured in gallons per sortie for each ship that is designated as air capable. The number of sorties is designated by the user and can be changed in the event file.

2.5   Ordnance Usage

Ammunition was divided into several components, all of which can be changed by the user. The use of weapons is controlled by the user through input

into the event list. BFORM requires that a specific weapon be fired by a specific ship. This makes input tedious for many sophisticated combat scenarios; however, the benefit of flexibility is obvious. A tactician may use any combination of ships and weapons that the user deems relevant in determining if there would be any logistical barriers.

6. Consolidation

Station ships can be replenished by shuttle ships in accordance with user defined events. The shuttle ship appears at a user defined position relative to the center of the formation and begins its search for station ships and combatants needing fuel, ordnance, etc. Depending on the location and relative speed of the shuttle ship, in comparison with CVBF SOA, replenishment of the station ship may or may not occur.

7. Model Output

The standard output of BFORM is quite similar to that of the next model to be described, RASM. An example of this is the listing of the Commodity History File displaying the chronology of commodity levels on each ship over time. A line of output is generated initially and at the end of the run displaying each ships' commodity level. More output is triggered by replenishment events and ordnance expenditures. The Event History file, which provides chronologies of the movement in and out of the combatants' designated patrol areas, ordnance expenditure, and other activities of CVBF units, is another of the standard output documents available for the analyst to use.

One of the most useful output documents of BFORM is the Station Time file. This file lists both the maximum time spent out of station and the total time spent out of station for each combatant. BFORM is the only model of the three that renders this format for time off station. RASM only computes that average time off station for all the combatants summed together. In order to compare the two

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models, only the average time off station for combatants was used in the evaluating the two models. There is a benefit to knowing what the maximum time off station is for each combatant for the logistician can better determine how a wide dispersion of forces will affect the battle group screen units.

Another standard output of BFORM is the summary statistics on commodity levels. This file calls for the model to calculate and display the mean, standard deviation, and minimum level of each commodity on each ship during the run. The most valuable of these statistics is the minimum level. If a ship reaches an unacceptable level for a commodity during a run, it may indicate a critical weakness in the logistic supportability of a mission. An obvious example of this is when a cruiser runs low on surface-to-air missiles(SAMs) after several days of combat. The ability to replenish SAMs quickly may be crucial to the survival of the cruiser or the carrier it is escorting. Only BFORM calculates this statistic. RASM will display a note at the end of a phase in its event listing as to whether a ship has exhausted any of its commodities, but it does not specify which commodity has been exhausted. RSRG/SOS only gives a gross estimate of the average for the entire task force. The minimum level at the end of a run will be used as an MOE in comparing BFORM with RASM.

8. Summary of BFORM

Overall BFORM uses several good approaches and offers the most detail in viewing the logistical processes in a battle group. There is great flexibility in the definition of events and ship characteristics. The analyst can view a wide range of scenarios, ship composition, etc., to see what effect logistics will have on the battle force. The model can be used on any ship that has an IBM or IBM compatible computer and does not require any knowledge in computer programming. However, there are quite a few weaknesses to the model that kept it from being as great an aid to fleet or program analyst as it could have been. The model

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assumptions tend to make the model overly optimistic in several ways. By not allowing for attrition during a run, the model assumes that the CLF ships will not come under attack even when replenishing in a combat area. This can be remedied by running the model in parts. This would call for the user to divide the scenario into time intervals before and after CLF ships or combatants had been lost or damaged due to combat. Taking the ending inventories from one time interval and re-starting the problem from that point with fewer ships give the analyst an idea of what effect the attrition of CLF ships will have on the battle force. This process of running the model many times to find the best solution for the scenario is of course a tedious one.

Another optimistic assumption is the constant reliability of all replenishment rigs on the CLF ships. It is unrealistic to believe that the CLF replenishment rigs would be 100% reliable or constant at any rate throughout most transits. Conversely, BFORM underestimates the replenishment process by omitting to model vertical replenishment (VERTREP) operations. Vertrep has been a significant player in the logistical support of battle force operations and there are times when its effects will be significant.

The usability of the model is lessened by the use of rectangular coordinates for input of the ships' positions. This does not affect the model results; however, it is inconsistent with how ships' positions are typically assigned. In addition, several key definitions are badly explained or missing in the user manual. The shuttle ship console operation, TTRANS, and TUNREP are examples of these definitions. It is hard for an analyst to evaluate the validity of a model without such information.

BFORM's CLF ship scheduling algorithm is also too shortsighted. After an unrep the model only looks for the next ship to be replenished and does not create an optimal route for the CLF ship to take when passing from one combatant to another. BFORM results show an unrealistically long time alongside for

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replenishment operations. In some cases the model allowed ships to be alongside for almost 24 hours.

Another significant shortcoming of BFORM is the limited capacity for ships (< 30) and events (<177) that can be modelled in each run. In today's multi-carrier operations, it is conceivable that more than 30 ships will be involved. As the number of ships grows, the number of events also increases to capture the intricacies of the the battle force operations.

The next model to be described, the Replenishment-At-Sea Model (RASM), reflects many similarities to BFORM in the structure of its input and modelling of battle force events.

B. REPLENISHMENT-AT-SEA MODEL (RASM)

1. Background

RASM is another deterministic computer model developed as an aid in measuring CLF capabilities. The program, developed in 1986 at the Center For Naval Analyses (CNA) for in-house use, was developed on a VAX 11/785 and uses a Simscript II.5 compiler. The model was developed to enable the user to analyze the following topics [Ref. 4:p. 2]:

a) Examine the amount of material expended and replenished by a battle force during an operation.

b) Examine the number of CLF ships needed to support a battle force operation.

c) Examine the mix of CLF ships needed to support a battle force operation.

d) Examine the tactics used by the CLF ships to replenish a battle force.

e) Examine shuttle ship requirements in support of station ship and CVBF mission needs.

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RASM is an operational level model, with aggregated results reflective of the battle force requirements as a whole. However, each ship is individually identified in order to determine the appropriate fuel usage curves, ordnance expenditures, etc. Transfer rates for fuel, ammo, and other commodities are determined by the user. Each phase has its own SOA, commodity consumption, and replenishment scheduling peculiarities. For example, unreps will not be initiated during a raid or a storm. Phase characteristics are summarized in Table 2.1 [Ref. 4:p. 11].

TABLE 2.1   JP-5 USAGE RATE BY PHASE

Phase number	JP-5 consumption[3]
1	Light
2	Moderate
3	Heavy
20(storm)	Light
30(raid)	Heavy
40(strike)	Heavy

---

[3]The terms light, moderate and heavy refer to user defined fuel usage rates in barrels (42 gallon/barrel) of fuel per day. Specifically for this thesis, they will refer to (1) light = 3500, (2) moderate = 4700, and (3) heavy = 6000 barrels per day used by each aircraft carrier.

2. Assumptions

Several assumptions are made to enable users to access and change the RASM's scenarios for analysis of various logistic and tactical situations. The assumptions also tend to make the model appear conservative in estimating the battle force CLF capabilities. Similar to BFORM, the model will not underestimate the number of ships needed to support a logistic scenario.

Major assumptions are as follows:

a) Battle force positions do not change, and therefore, a ship neither joins nor leaves the battle force.

b) Battle force is totally dependent on the unrep for major commodities.

c) Replenishment operations take precedence over all other evolutions except for phases with storms, raids or strikes.

d) All units maintain the same course throughout the simulation.

e) Replenishment equipment reliability remains constant throughout the run.

f) Only carriers and CLF ships can transfer fuel to other ships.

g) Ships will travel to their unrep station at their top speed and return at the same pace. This is true regardless of the replenishment mode since ships will fall out of their home station when they change from CVBF SOA to unrep speed.

h) Combatants seeking replenishment of more than one product areprioritized as shown in Table 2.2 [Ref.2:p.30].

i) Every ship has a beta and delta inventory of the commodities that it can carry. The beta inventory is that amount of a commodity that the ship holds for it's own use. The delta inventory is the amount of a commodity that the ship holds so that it can replenish another ship. Since RASM is the only model that divides commodities in this fashion, only the carriers and CLF ships were given any amount for delta (deliverable goods) inventories.

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TABLE 2.2   CHOICES FOR UNREP BASED ON PRODUCT

NEED

Product need	First	Second	Third	Fourth	Fifth
None		-	-	-	-	-
POL		AO	MP	CV	-	-
STO		AFS	MP	-	-	-
ORD		AE	MP	-	-	-
POL,STO	MP	AO	CV	AFS	-
POL,STO	MP	AO	CV	AE	-
ORD,STO	MP	AE	AFS	-	-
POL,STO,ORD	MP	AO	CV	AE, AFS	

j)   If fuel is needed by a "small boy" it will acquire it from a CV as a last resort, and only one ship can be replenished at a time from the CV.

k)   Only CLF ships and CVs can perform "Self-unrep" between their beta and delta inventories of fuel. These evolutions take only twenty minutes and do not interfere with battle force operations.

l)   Transfer of commodities is done simultaneously. Total transfer time is the maximum of the individual commodity transfer times plus 42 minutes to account for final maneuvering, rigging and unrigging.

m)   Battle force composition remains constant throughout the simulation run.

3. Kinematics

RASM assumes that all the items carried by a ship are of equal importance. There is no priority scheme as in BFORM. Therefore, replenishment is needed when the inventory of any commodity has been depleted to its reserve level. The reserve level is the minimum acceptable inventory defined by the user for each item for each ship of the battle force. RASM computes the expenditure rate of each item in each ship's inventory during every phase of its operation. The replenishment of the battle force ships is controlled by a SIMSCRIPT event called the Battle Force Logistics Coordinator (BFLC). BFLC has two types of logic commands: the Service (Gas) Station and the Delivery Boy modes. Overall concepts are the same as discussed in BFORM: however, their implementation has significant differences.

With Service (Gas) Station tactics, the combatants travel to the CLF ship for replenishment when one of their inventories nears reserve level. The BFLC selects a CLF ship for the combatant at the time the request for replenishment is made. This decision is based on the type and number of CLF ships available and their ability to replenish the combatant. Combatants unable to be replenished immediately wait on a first-come, first serve basis until the opportunity to replenish arises. Once replenishment is completed, a combatant immediately returns to its home location.

In Delivery Boy tactics, the CLF ships travel out to the combatants and replenish them at their station. Consequently, the BFLC makes replenishment decisions based on the availability and position of the CLF ships. When a CLF completes replenishment, the BFLC immediately selects the ship it will replenish next. The decision is based on the replenishment index, Z_i. This index, Z_i, quantifies the desirability of each ship for replenishment. The unrep candidate ship with the lowest Z_i is selected. The base value of Z_i is intership distance (the straight-line distance between the current location of the available MLSF ship and the home location of the candidate). The base value is then modified to reflect other considerations, such as the need for replenishment, time to close, and the suitability for unrep. These Z_i values are calculated at the end of an unrep and at each phase transition. This approach to scheduling CLF ships in battle force operations is very similar to that of BFORM. In both models, the next ship to be replenished is determined at the end of a CLF ship replenishment. In real world operations, CLF ships are normally given a route or schedule for several ships in the battle group at one time. They do not take a travel myopically from one position in the battle force to another as is modelled in either BFORM or RASM.

4. Fuel Usage

RASM determines its DFM usage by use of a cubic equation. The coefficients of the equation are stored in a data file for access by RASM according to ship type. Each equation's solution is carried to the fourth decimal place in determining the fuel consumed per hour by each type of ship. The amount of consumption estimated by this method accounts for some of the difference between RASM and BFORM results. Minimum and maximum burn rates are given for each ship just as in BFORM. Since ships do not travel at the speed specified by the SOA for various tactical reasons (eg.zig-zag maneuvering), an additional constant, "BUMP", is provided for the user.

Jet fuel (JP-5) is consumed according to the operational tempo designated by the user. The consumption rates : light(3500 barrels per sortie for each carrier), moderate (4700 barrels) and heavy(6000 barrels), will be used in the scenario (a barrel equals 42 gallons in RASM).

5. Stores

RASM assumes that every ship consumes stores at a constant rate and that all ships within a given type consume stores at the same rate. The user inputs the stores consumption' rate for each ship type. In general, stores consumption has not proven to be a driving factor in most replenishments. It is only included in RASM so that the model can be used on a wider range of scenarios and so that more logistical questions concerning battleforce logistics can be answered.

6. Ordnance Expenditure

RASM, similar to BFORM, differentiates between a variety of weapons and the ships that can fire them. RASM defines two categories of phase type in which ships expend weaponry: raid/strike and regular. In the regular phases, ships expend ordnance in proportion to the ships' capacity. This calculation is shown in

Figure 2.2 [Ref. 2:p. 11]. If a ship doesn't have the type of ammunition that is being fired, then its U_{ijk} is zero.

$$BF.EXP_{jk} = \text{the number of ordnance item "j" the}$$
$$\text{entire battle force expends in phase "k"}$$
$$U_{ijk} = \text{usage on ship "i" of item "j"}$$
$$\text{during phase "k"}$$
$$T_k = \text{the duration of phase "k"}$$
$$I_{ij} = \text{the capacity of item "j" on ship "i"}$$
$$n = \text{the total number of ships}$$
$$\text{in the battle force}$$
$$U_{ijk} = \frac{BF.EXP_{jk}}{T_k} \times \frac{I_{ij}}{\sum\limits_{i=1}^{n} I_{ij}}$$

Figure 2.2 Ordnance Expenditure During Regular Phases

For the threat or strike phase, three parameters are needed to determine ordnance expenditures: (1) threat axis; (2) threat region along the "threat strike" axis that encompasses those ships expected to "bear the burden" of the attack; and (3) "BURDEN", the fraction of $BF.EXP_{jk}$ that the ships in the threat strike region are responsible for expending as seen in Figure 2.3 [Ref 2:p. 12].
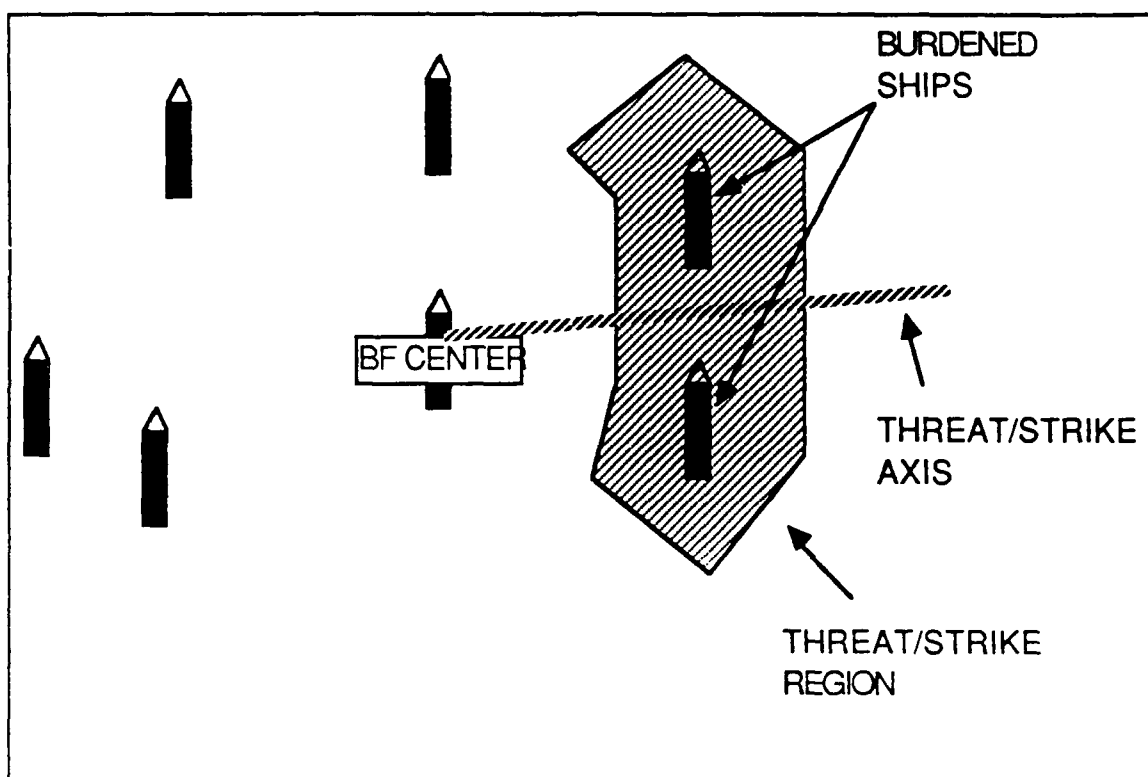
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Figure 2.3 Threat/Strike Region and Axis

For ships inside the threat/strike region, the ordnance usage rate of threat/strike item ij on ship i is and for ships outside the region during a raid/strike phase, the equation is as shown in Figure 2.4 [Ref. 2:p. 13].

$$U_{ijk} = BURDEN \times \frac{BF.EXP_{JK}}{T_K} \frac{I_{ij}}{\sum\limits_{i=1}^{n1} I_{ij}}$$

n1 = number of ships inside threat/strike region

$$U_{ijk} = \left[(1\text{-}BURDEN) \times \frac{BF.EXP_{jk}}{T_k} \right] \frac{I_{ij}}{\sum\limits_{i=1}^{n2} I_{ij}}$$

n2 = the number of ships outside the threat region

Figure 2.4 Ordnance Expenditures During Threat/Strike

7. Consolidation

RASM provides for the replenishment of the station ships by reviewing the need for commodities on CLF ships at the end of each unrep. The consolidation event occurs when any commodity is found to be below the user defined reserve level. If the level of POL, STO or ORD falls below the specified value (POL.CONSOLE, STO.CONSOLE or ORD.CONSOLE), the model replenishes the CLF ship from a constructive shuttle ship at the rate that the CLF ship receives that commodity. As if by magic a shuttle ship will appear next to the station ship and begin to replenish it. This is a less realistic method of modelling the shuttle ship than is in BFORM. In BFORM, the shuttle ship had to search for the station ships from a point designated by the user. This method does, however, give the analyst an approximation of when the shuttle ships need to arrive and the amount of each commodity that is needed. This does not make up for the artificiality of the model in that there is no movement by the CLF ship out of its battle force position during the consolidation operation. The CLF ship will remain in the battle group while replenishing just as in the BFORM algorithm. The programmers of RASM claim that it is a conservative model which gives the best conditions for the CLF to operate. Thus, if RASM indicates a major shortcoming in the logistical supportability of a mission, then there is good reason to doubt that the operation would go smoothly in reality.

8. Model Output

Some of the output files are very similar to BFORM. An Event history, Commodity level history (both delta and beta), and Final inventory(both delta and beta) levels are available. As mentioned earlier, the time of arrival and the amount delivered by shuttle ships are displayed in the Summary file for each run. The Summary file also documents the average time spent off station for each combatant.

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RASM has aggregated summaries and summaries by ship of the final inventory level for the battle group(s) modelled in the scenarios. RASM requires that the analyst examine many sheets of output to evaluate simple estimates of the CLF ships logistical effectiveness. Measures such as the number of unreps, time spent off station by individual ships, and commodity minimum inventory level are not readily available from the model and require scanning the event list to obtain an answer.

9. Summary of RASM

RASM and BFORM are of equal capability in many ways. Both models allow the user a lot of input in designing scenarios and capabilities to be investigated. As mentioned earlier, some of the output of these two models are also quite similar. The artificialities of modelling the replenishment process in BFORM are present in RASM as well. VERTREP operations, CLF attrition, and replenishment rig reliability are also ignored in RASM. Neither RASM nor BFORM present any graphical results. The graphs presented later in this thesis were all generated off-line from these programs.

There are quite a few differences between the models' usability. RASM requires that the user has access to a VAX computer with a SIMSCRIPT compiler. A working knowledge of SIMSCRIPT is also needed to use the model. An advantage of using the VAX is that the model runs quickly and is unrestricted in the number of ships that can be modelled in each scenario run. Thus, the number of different scenarios that can be run is greatly increased in comparison to BFORM.

RASM can provide the user with an assessment of the logistical supportability of a battle group, which is likely to be higher in the judgment of the author. Validation of model results with fleet logistic data will have to be done to determine the accuracy of RASM estimates.

The last model to be described, RSRG/SOS, has little similarity to the other two models. Its modelling methodology of CLF processes is directed at shuttle ships more than station ships.

C. RESUPPLY SEALIFT REQUIREMENTS GENERATOR/SHIP ONLINE SCHEDULER(RSRG/SOS)

1. Background

RSRG/SOS was developed in 1988 by the Computation, Mathematics, and Logistics department at David Taylor Research Center, (DTRC), Carderock, Maryland under tasking from the Afloat Logistics Branch (OP-403). It is a deterministic, low resolution computer model written in Fortran for the IBM PC. RSRG claims to use Joint Operation Planning System(JOPS) logistic planning factors to assist in determining the requirements for a task group as described by the user during the scenario input phase. RSRG/SOS was developed for the Fleet logistic planner and battle force logistic planner as an aid in determining logistic requirements to meet tactical plans. The three major objectives [Ref. 5:p. 2] of RSRG are:

a) To give fleet planners a tool to analyze their combat logistics force (CLF).

b) To create a requirement generator that is both user-friendly and economically efficient.

c) To assist analysts in the generation of official Navy planning factors from the Logistics Factors File (LFF), when possible.

The output from RSRG is used by the SOS to estimate a shuttle ship schedule (not the optimal schedule) for replenishing the task group(s) [Ref. 6:p. 1]. Figure 2.5 below is an example of the Cargo Shipment Requirements output that describes how the model presents the shuttle ship schedule to the user.

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```
CARGO SHIPMENT REQUIREMENTS.


ORDER                              ORIG          DEST
  NO       AMOUNT                  LOC           LOC        RDD


   1            66   KBBL-JP5   GUAM             MODLOC1    8.0
   2           267   STS-THR    GUAM             MODLOC1    12.0
   3          1813   STS-THR    GUAM             MODLOC1    12.0

SELECTED SHIPPING ASSETS.

SHIP       SHIP           START      START
NUMBER     NAME           LOC        (DAYS)
   1       *AO      1     GUAM       2.6
   2       *AET     1     GUAM       -1.4
   3       *AET     2     GUAM       -1.4
```

Figure 2.5 Sample Output from RSRG/SOS

The output of SOS can be used by analysts to evaluate the feasibility and ease of supporting a particular OPLAN, and to determine whether it could be supported. Another benefit from this model is that it can be used for planning the procurement of shuttle ships and analyzing their design requirements. Output from RSRG/SOS is also useful in estimation of the effect of varying the distance between the battle force operation area and the nearest ALSB.

2. Assumptions

Since the RSRG/SOS is a low resolution model, many assumptions are implicit. For example, stores usage rate is determined by the JOPS planning factors and is not related to the mission, environment, or condition of the ship. Other notable simplifying assumptions of RSRG/SOS are as follows:

a) Course and speed remain constant (i.e. cannot be input, are not modelled)

b) Vessel speed and course do not affect the need for shuttle ships.

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c) Environment, replenishment equipment reliability and other random factors do not affect the need for shuttle ships.

d) The tactics (Delivery Boy or Service (Gas) Station) used by the station ships in the task force do not affect the replenishment problem for the shuttle ships.

e) RSRG/SOS evaluates fuel usage by the multiplication of JOPS planning factors and the number of days in the operation.

f) Cargo is not delivered to the task group during transit from one location to another.

There is little internal to the battle force, whether it be transfer rate or battle force SOA, that has an effect on this model. Other variables that can be manipulated by RSRG/SOS are listed in Table 2.3.

3. RSRG/SOS Input

As was the case in the previous models, RSRG/SOS require input of the type and number of ships that are in the task group(s). The user also must define the starting level of the commodities in the battle force. In addition to these similar inputs, RSRG/SOS require information in the following areas that are not included in BFORM or RASM [Ref. 6:p. 16]:

a) Distance between the location of the battle group's operation and the nearest ALSB.

b) The type and number of shuttle ships available.

c) The location from which the shuttle ships depart.

d) The minimum allowable ship load (MASL)[4].

e) The acceptable waiting period for loading shuttle ships.

f) Ship type preference in scheduling the sequence of deliveries.

g) The ship loading capacity of the ALSB.

h) The number of ships that can be serviced at the area of battle group operation.

i) The speed of the shuttle ship.

j) The cargo mix of the shuttle ship.

4. RSRG/SOS Output

RSRG/SOS is much different form RASM and BFORM. Since the model is a theater level model, no information is available on the individual ship commodity level over time. Various reports that are available are as follows:

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[4]MASL refers to the level of battle force supplies ordered that cause a cargo delivery to be scheduled.

a) Cargo Level At Each Task Group (Battle Group)- aggregated level of each commodity during run.

b) Ship Utilization - use of the shuttle ships during a run.

c) Transfer Point Activity - ALSBs utilization during a run.

d) Shipping Schedule - list of trips by shuttle ships scheduled by SOS.

e) Delivery Deletions - cargo requirements that had no corresponding trip in the Shipping Schedule.

f) Convoy Information - summary of convoy formation parameters.

5. Summary of RSRG/SOS

RSRG/SOS is the only model of the three that examines the theater level effect on fleet operations that are based on the utilization of shuttle shipping assets. It is also the only model that attempts to weigh the effect of geography in calculating logistical supportability of a mission.

RSRG/SOS does not give the user the best solution or schedule to meet a task group needs. In order to find an optimal policy for meeting the logistical objectives, an interactive approach similar to that used in BFORM and RASM should be taken. That is, the model must be run several times using different MASLs. shuttle ship types and numbers, etc. to find the best solution to support task group operation.

The most prominent shortcoming of RSRG/SOS is that its lack of detail at the battle force.(ie. resolution is too low). By ignoring the battle force kinematics, RSRG/SOS provides results that are too coarse for evaluating mission feasibility or ship capability. There is no way to determine if any ship(s) runs out of a commodity during the run. The time off station for a ship is not available either. In fact, very few MOEs are measured in RSRG/SOS.

The program is very easy to use and capable of being run on any IBM OR IBM compatible computer. Instructions are available both from the user manual

and on screen. A weakness of the user manual is that it does not reveal anything to the user about the mathematical modelling used in the program. Not only does this make the model harder to validate, but it also hinders the user's ability to draw conclusions on the results of the model.

In conjunction with RASM or BFORM, RSRG/SOS will be useful to devise a general idea of the role of logistics in future combat, when quick user friendly estimates of logistical effects are needed without great detail. By itself its utility is questionable. An approach that may prove useful is to use the model RSRG/SOS to determine a shuttle ship schedule for supporting the task force. This can be used as input for the other models to help determine the CLF's effect on the operation.

This concludes the description of the three models analyzed in this thesis. In Table 2.3 below a relative comparison of the models' inputs and outputs is provided.

TABLE 2.3 REPLENISHMENT MODEL CHARACTERISTICS

CONTROL VARIABLES	BFORM	RASM	RSRG/SOS
Numbers of ships in task group	yes	yes	yes
Commodity Thresholds	yes	yes	yes
Fuel (DFM) Consumption	yes	yes	PF[5]
JP-5 Consumption	yes	yes	PF
Ordnance Consumption	yes	yes	PF
Stores Consumption	yes	yes	PF
Replenishment Mode of Operation	yes	yes	no
Disposition of Units	yes	yes	no
Commodity (transferable)	yes	yes	yes
Commodity (non transferable)	no	yes	yes
Speed of Advance	yes	yes	no
Speed of Unrep	yes	yes	no
Weather	yes	yes	no
Duration of Run	yes	yes	yes
Shuttle Ship Visits	yes	yes	yes
Ship Priority Code	yes	no	no
Commodity Priority	yes	no	no
Geographic Location	no	no	yes
Location of Logistic Bases	no	no	yes
Transfer Rates for Commodities	yes	yes	no
Min. Allowable Shuttle Shipload	no	no	yes
Radius of Screen Ship Patrol Area	yes	no	no

OUTPUT	BFORM	RASM	RSRG/SOS
Event History	yes	yes	no
Commodity Levels	yes	yes	yes
Time Out of Patrol Area	yes	yes	no
Number of Unreps	yes	yes	no
Number of Shuttle Ships Used	yes	yes	yes
Ship Utilization History	sta ship[6]	sta ship	shut ship[7]
Transfer Point Activity	no	no	yes
Delivery Schedule	sta ship	sta ship	shut ship
Shuttle Ship Convoys Formed	no	no	yes

[5]PF Refers to Joint Operations Planning System Planning Factors

[6]sta ship refers to station ship

[7]shut ship refers to shuttle ship

III. MEASURES OF EFFECTIVENESS

In order to measure the effect of the CLF on a battle force's war fighting capability, several measures of effectiveness (MOEs) were decided upon. What is the purpose of the CLF? And, what do battle group tacticians think of the underway replenishment process? According to the Society of Naval Architects and Marine Engineers [Ref. 7:p. 1], the goal of the CLF ship was, *"...the safe delivery of the maximum amount of cargo in the minimum time....."* Vice Admiral G.C. Dyer, USN (retired) [Ref. 8:p. 2] aired a slightly different view of the CLF when he said that *"The logistic force must enable the fleet to do its job anywhere in the world by providing the fleet with endurance to stay on station."* Other prominent tacticians such as Admiral Arliegh Burke [Ref. 8:p. 2], during his tour as CNO, challenged Naval engineers to minimize unrep time. His belief was that time spent in replenishment situations left the force very vulnerable and that this time should be kept to a minimum . Finally, Captain Raymond Wellborn, ex-commanding officer of the USS Detroit (AOE 4), offered this opinion concerning the mission of the CLF ship [Ref. 11:p. 50]:

> *By maintaining ship readiness on station, our battle group's offensive and defensive postures are kept intact as is its ability to endure and be decisive. Each battle group ship that remains on station, mission-capable, precludes having a chain of replacement ship in transit, or in port, at different stages of readiness;*

All of these comments point to common concerns about the replenishment process. For a battle force to conduct sustained operations, it needs support in keeping commodities at a sufficient level to defend itself successfully and complete the mission. However, the need to replenish must be weighed against the

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vulnerability of the battle group when it is in this position. If there is benefit in maintaining the designed disposition of ships in a battle force, then the time combatants spend outside of those positions will degrade the effectiveness of the battle force as a whole. With these thoughts in mind, the several MOEs were considered and are used in this comparison of model results.

The first of the MOEs used is time off station. By observing the amount of time combatants spend off their assigned stations, a battle force commander may see gaps in the screen or grid coverage that resulted from excessive time spent in replenishing. The CLF models assume that the only time ships move from their designated patrol area is to replenish. Closely related to this MOE is the number of unreps conducted during a transit. This measure indicates the number of interruptions faced by battlegroup units and how distracted they are from their primary mission. The next two measures are related to the necessary commodities (fuel, ordnance, and stores) for conducting a mission. The aggregate inventory level for each commodity is an indicator of the amount of endurance that a battle force has remaining. All three models can be run for short time intervals to see how endurance changes over the course of the scenario. In this thesis, only the ending inventory level will be compared between the models. The last of the MOEs used is the minimum inventory level at the end of each scenario run. Though the minimum level reached during the run is a better indicator of a weakness in the battle force's ability to successfully complete the mission, only BFORM tracks this statistic. This is a notable fault in both RSRG/SOS and RASM. Measures like these form a basis for evaluation of the designs of CLF ships, disposition, and tactics.

In some ways all of the MOEs are very similar in their purpose. They all attempt to promote the relationship between logistical support and battle group warfighting sustainability and capability. For example, every moment a ship is in transit from its station, rigged alongside a CLF ship or returning to station, is a

moment that leaves the battle group as a whole in a more vulnerable state. Another important measure that reflects the CLF's influence on battle group operations is speed. Aside from the speed constraint caused by the carriers' search for wind to launch and recover aircraft, the battle group can move no faster than its slowest ship. Speed decreases in the battle force caused by slower CLF ships widen the limiting lines of approach for submarine attack, and thus leave the battle force more susceptible to it. A CLF ship's speed is also important in determining how dispersed the force can be. Modeling different dispositions with a will indicate a battle group can be spread before ti becomes unsupportable logistically.

The number or percentage of weapons available is also of great concern to any battle group commander. How much of an increase to the storage capacity on a CLF ship is needed? The ability of a battle group to travel quickly can also be of great tactical importance and a slow replenishment ship might be the *"Achillies heel"* of which a commander must be aware. The time needed to travel between ships could narrow the dispersion of forces available to the battle group commander or the length of time that the battle force ships will be below a desired level of inventory of ammunition.

The three CLF models provide answers to some of the questions that concern battle force capability, but they are not always straight-forward. The major drawback of these models is that they call for the user to search through long event listing to obtain much of the data to conduct an analysis using the MOEs discussed. With the models and MOEs chosen, the next phase of the analysis was choosing the scenario to use. The following chapter will discuss the experimental procedure used.

IV. EXPERIMENTAL PROCEDURE

The focus of this study was the comparison of model results when run in similar circumstances. Since the input for running both BFORM and RASM was so similar, this was not a problem. Difficulty arose in trying to place RSRG/SOS in the same context as the other models. As a consequence of this, the scenarios carried much more detail than RSRG/SOS required and may have biased the analysis against it.

The scenarios used in comparing these models were designed to be generic in nature. And, in order to keep the study unclassified nature, the parameters and ship types do not represent U. S. Navy vessels. Table 4.1 lists the ships, their top speeds, designated patrol stations, and loadout capacities. For all runs a ship was considered inside its patrol area as long as it was within 2nm of its designated patrol station.

For simplicity in running these models, aviation fuel consumption by cruiser and destroyer helicopters was not considered, even though both BFORM and RSRG/SOS allowed for this reality. Missile usage was also simplified by designating all SAMs(surface to air missile) and AAMs(air to air missile) as the same type among ships. (All of the models allow for a number of different type missiles to be named and tracked as any other commodity.) Gun ammo and stores were ignored in these runs, since they could be transferred rapidly via vertical replenishment, and are had not usually a constraining element in the battleforce logistic evolutions.

TABLE 4.1   DISPOSITION AND COMMODITY LEVELS.

SHIP	SPEED	RNG / BRG	DFM	JP-5	SAM	AAM
CVN-1	32	50/270	0	2500	0	500
CG-1	32	60/270	560	0	90	0
CG-21	32	50/230	560	0	90	0
AOE-1	26	00/000	7500	2000	154	500
CV-2	32	60/000	2400	2000	0	500
CGN-2	32	20/000	0	0	80	0
DD-2	30	110/020	500	0	0	0
DD-22	30	100/010	500	0	0	0
DD-23	30	100/355	500	0	0	0
DD-24	30	100/340	500	0	0	0
DDG-2	30	100/000	500	0	60	0
DDG-22	30	80/345	500	0	60	0
DDG-23	30	80/015	500	0	60	0
CG-22	32	80/320	560	0	90	0
CG-23	32	80/040	560	0	90	0
AOE-2	26	60/340	7500	2000	154	500
CVN-3	32	50/090	0	2500	0	500
CG-3	32	70/090	560	0	90	0
CG-32	32	60/120	560	0	90	0
DD-3	30	40/160	500	0	0	0

Figure 4.1 provides a graphical representation of the formation used in this study. The Fuel curves used to model DFM consumption of the battle force. are displayed in Figure 4.2 below. An unclassified version of equations like those found in RASM were used to develop fuel curves for the ships in these scenarios. The consumption rates were then taken at speeds from 12 to 32 knots at 2 knot increments for each ship. These values were rounded off to whole gallons and used as input for the BFORM model.
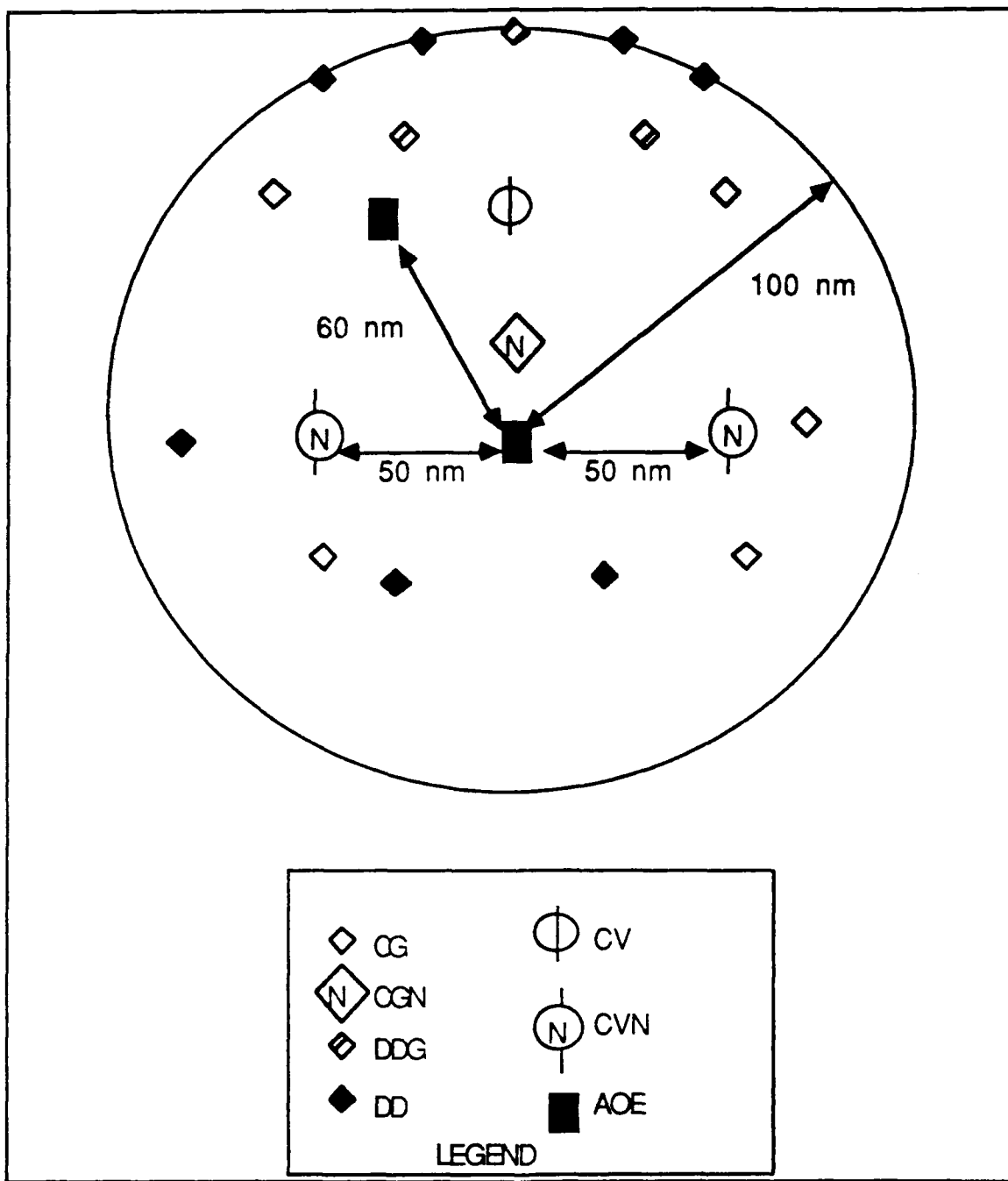
Figure 4.1 Task Force Formation

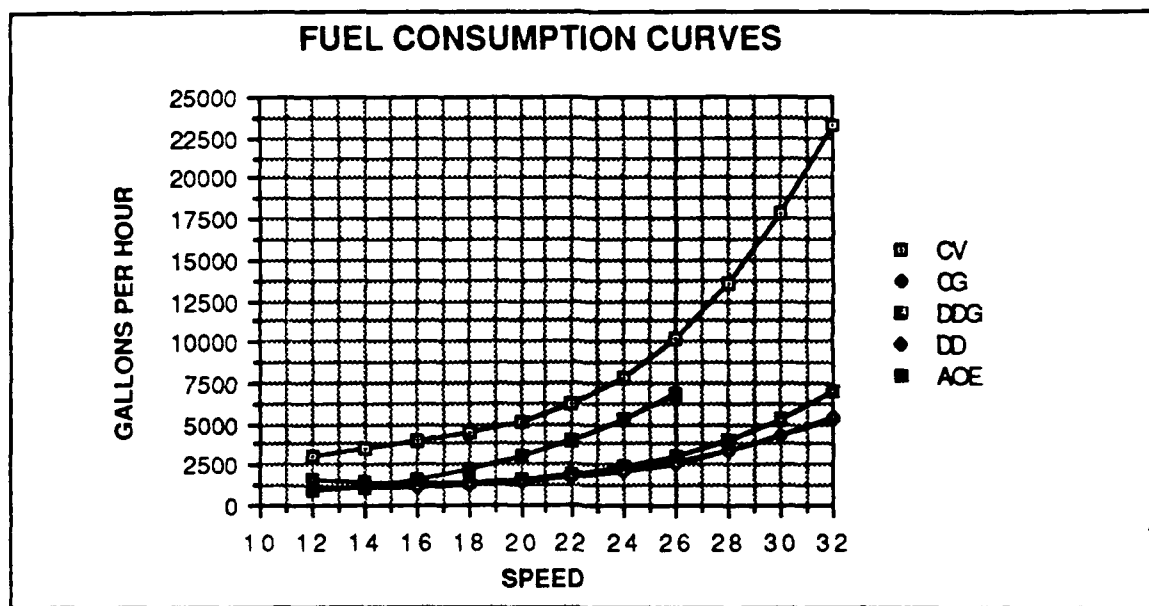**FUEL CONSUMPTION CURVES**

Figure 4.2   Task Force Fuel Curves

Transfer rates between CLF and combatant ships were assumed to be 295,000 gallons per hour for both JP-5 and DFM. Consumption of JP-5 was 1870 gallons per sortie with 135 sorties at high levels of aviation activity, 105 sorties at the moderate level, and 80 sorties at the low level. The threshold level was set at 70 % for POL and 50 % for ammunition in each model for all cases.

Several cases were studied to evaluate whether or not the models provided essentially similar results or not with various circumstances. The variable in the tactical situation was combat occurrence during the run. The speed of advance for the CVBF and the mode of unrep were also varied in the model. RASM is the only model that allowed for changing the unrep policy depending on the time period (phase) of the scenario. The last variable examined was the dispersion of the group. In the first eight cases the farthest a screen ship was from the center of the formation was 100 nm. For the the more dispersed formation the outer screen ships were pushed out to 125 nm, while the other units moved to positions a factor of one and one-half their original distance from formation center.

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Table 4.2 briefly describes each of the eight test cases that were run in this thesis for each model.

TABLE 4.2   SCENARIO DESCRIPTIONS

CASE N	COMBAT, CVBF SOA, UNREP MODE, DISPERSION
1	NO COMBAT, SLOW SOA, GAS STATION, 100 NM
2	NO COMBAT SLOW SOA, DELIVERY BOY, 100 NM
3	NO COMBAT, FAST SOA, GAS STATION, 100 NM
4	NO COMBAT, FAST SOA, DELIVERY BOY, 100 NM
5	COMBAT, SLOW SOA, GAS STATION, 100 NM
6	COMBAT, SLOW SOA, DELIVERY BOY, 100 NM
7	COMBAT, FAST SOA, GAS STATION, 100NM
8	COMBAT, FAST SOA, DELIVERY BOY, 100 NM
9	COMBAT, SLOW SOA, GAS STATION, 125 NM
10	COMBAT, SLOW SOA, DELIVERY BOY, 125 NM
11	COMBAT, FAST SOA, GAS STATION, 125 NM
12	COMBAT, FAST SOA, DELIVERY BOY, 125 NM

The first setting (cases 1 through 4) were 13 day transits with no combat action at both fast and slow SOAs (10 and 15 knots). Since the carriers sprint and turn quite often to support flight operations and return to PIM, it was assumed that all CVs/CVNs would travel at 10 knots above battle force SOA in the fast and slow cases. The other ships were modelled as exceeding SOA by only five knots to account for them patrolling their stations. The large difference between SOA and the carriers was chosen so that the models would be stressed in their use of the limited CLF assets.

The second setting (cases 5 through 12) involved a quiet transit leading up to several days of combat, followed by egress from the battle area while in combat. A summary of the events for the combat cases is provided in Table 4.3 .

TABLE 4.3.   DETAILED DESCRIPTION OF COMBAT SCENARIO

DAY	WEAPON EXPENDITURE	FLIGHT OPERATIONS
1-4	no CVBF weapons fired	low level
5-6	10% of CVBF weapons fired	moderate level
7	50% of CVBF weapons fired	high level
8-9	30% of CVBF weapons fired	high level
10-13	20% of CVBF weapons fired	moderate level

RSRG/SOS required different input than the other two models. The setting was still thirteen days with both combat and non-combat runs, but the geographical area and location of the nearest Advanced Logistic Support Base (ALSB) had to be specified as well. The model gives a choice of five locations from which to choose and requires the distance and amount of time spent in operation area that the user defines. In these runs, the Pacific option was used with a operation area called MODLOC1 located 900 nm from GUAM (the nearest ALSB).

V. COMPARISON OF MODEL RESULTS

A pilot run was conducted in which the ships were given unlimited fuel capacity and not forced to unrep to see roughly how similar the models were and to verify their internal consistency. This test run was compared with a careful, hand calculated fuel consumption estimate to judge the accuracy of the models. The comparison is presented in Figure 5.1. Other figures displayed in the next two chapters indicate the trends of the results and are not meant to indicate linearity of these CLF models.
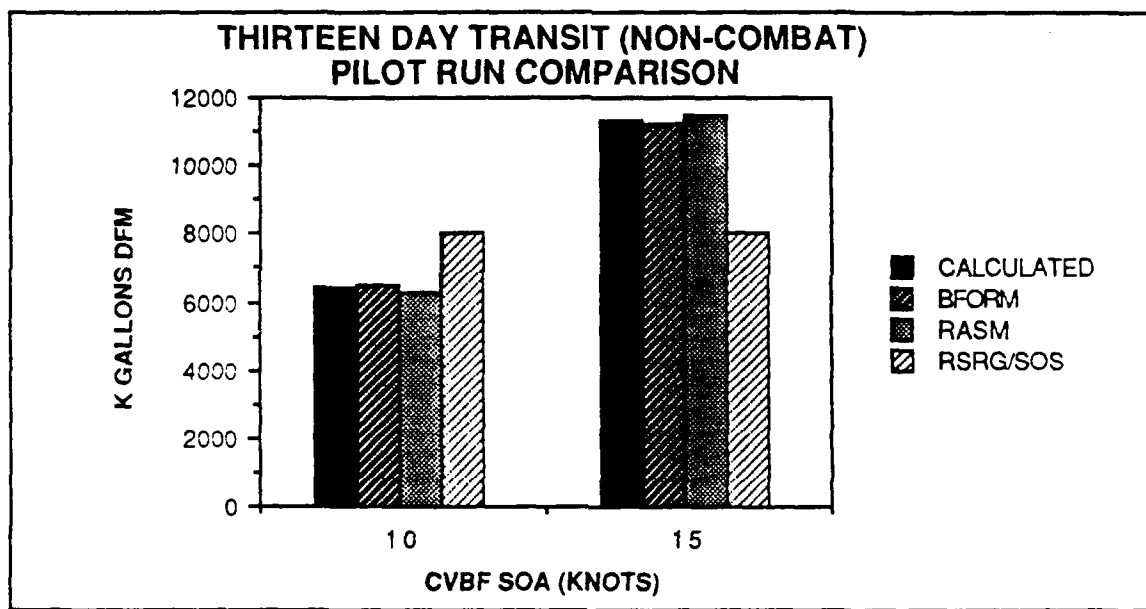
Figure 5.1 Pilot Run Comparisons

Note that RSRG/SOS results do not change as the CVBF SOA changes. As seen in Figure 5.1, the same result comes for both low and high SOAs. By design, RSRG/SOS examines the theater picture and ignores many factors that effect the battlegroup logistic performance. For this analysis, the RSRG/SOS's planning factors assume that the carrier will operate at approximately 27 knots continuously, and the other ships operate at about 15 knots. Due to RSRG/SOS design as an

aggregated theater level logistic model, comparisons were not possible in most cases. Model results were compared, however, between RSRG/SOS and the other models whenever possible.

In general, BFORM results showed a more conservative trend and more consistent results in comparison with RASM and RSRG/SOS. In Figures 5.2 and 5.3, the amount of DFM available in the CVBF is shown, at the end of the Gas (Service) Station and the Delivery Boy scenarios. In BFORM it drops off much more quickly as SOA increases relative to the other models. Also observe, that the amount of DFM loadout capacity remaining is less, regardless of the unrep mode, in the BFORM runs [8]. Note that all the following figures, "G/S" stands for Service(Gas) Station mode and "D/B" stands for Delivery Boy mode.
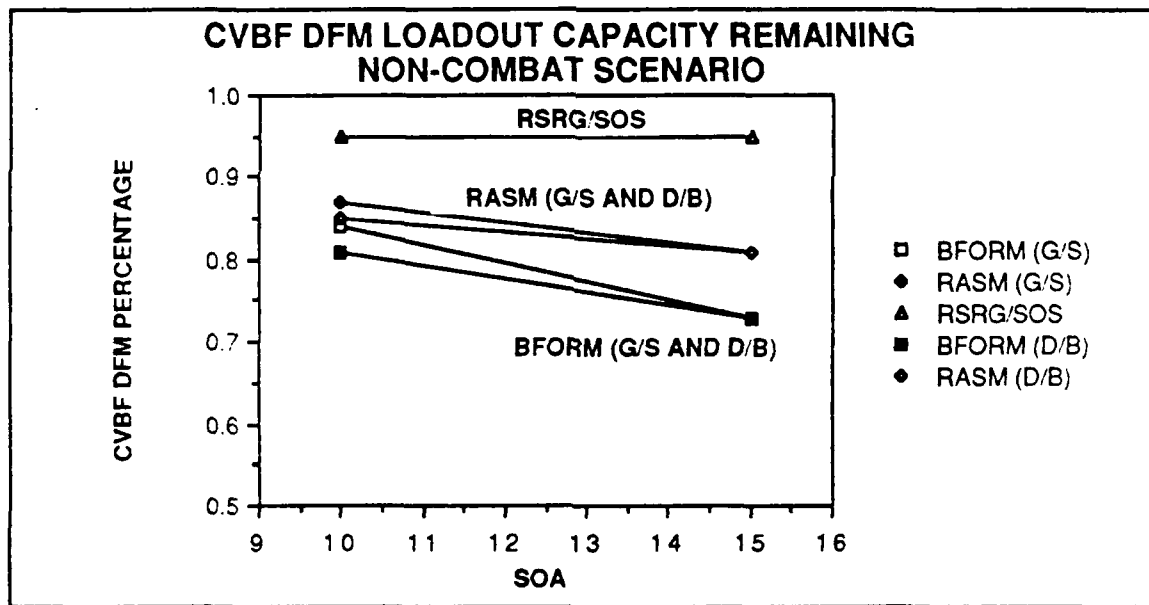
Figure 5.2 DFM Capacity from CASES 1 - 4

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[8]Loadout capacity remaining is the sum of all the ending commodity levels for all the ships in the battle group. This includes the station ships, but not shuttle ships.
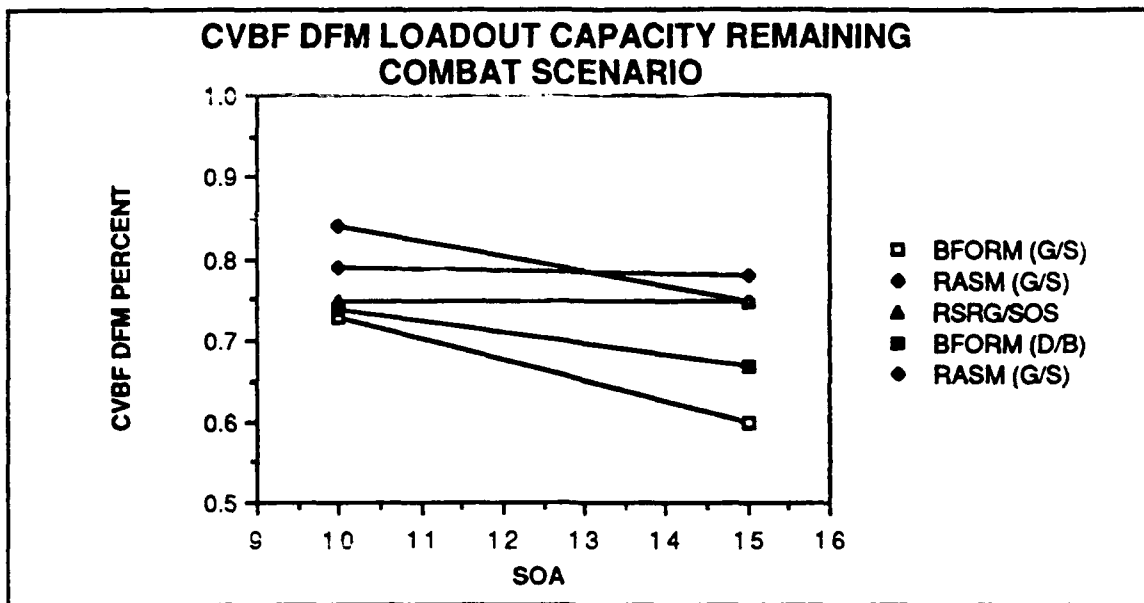
CVBF DFM LOADOUT CAPACITY REMAINING COMBAT SCENARIO

Legend:
- □ BFORM (G/S)
- ◆ RASM (G/S)
- ▲ RSRG/SOS
- ■ BFORM (D/B)
- ◆ RASM (G/S)

Figure 5.3 DFM Capacity from Cases 5 - 9

Figures 5.4 and 5.5 show how aviation fuel capacity is affected by the speed and degree of battle force combat operations. As expected, the combat scenarios with their fluctuating sortie levels, displayed a greater rate of consumption of JP-5 than did the non-combat cases. The steeper decline in JP-5 available in Figures 5.4 and 5.5 also indicates that the BFORM results were more sensitive to higher speeds than were the other models. The reason for this difference was due to the lower number of unreps completed by the CLF ships with aircraft carriers in the BFORM results.
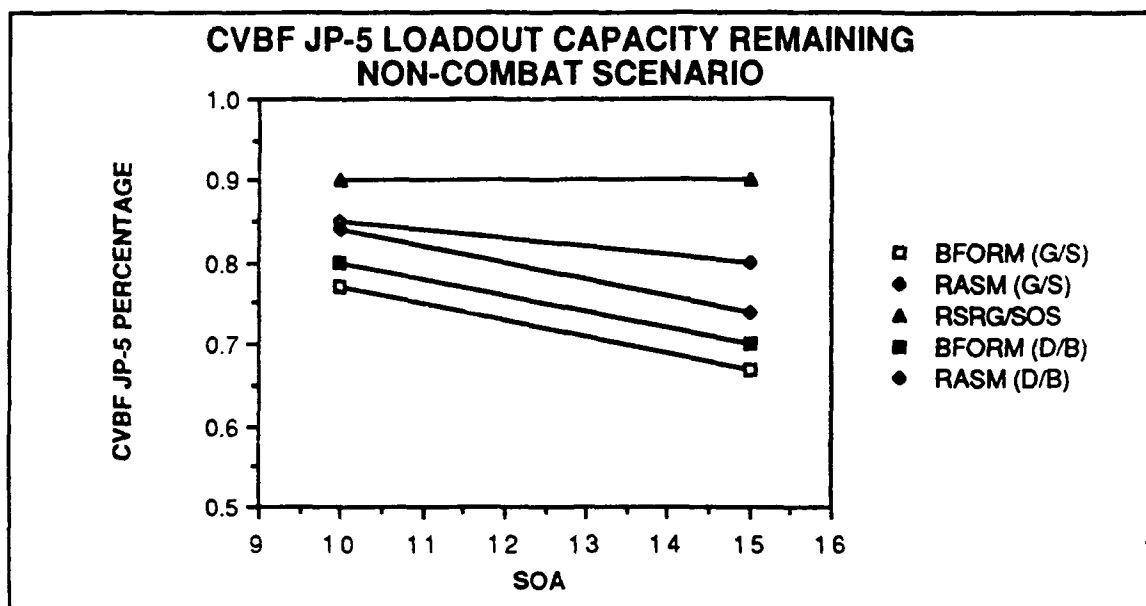
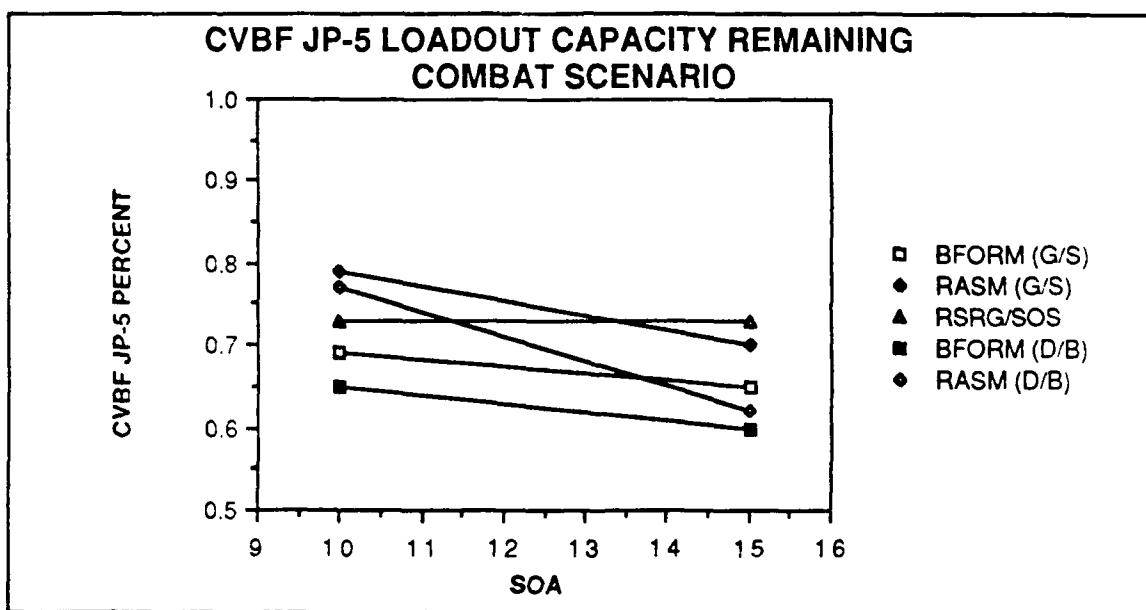**Figure 5.4 JP-5 Capacity from 1 - 4**

Figure 5.5 JP-5 Capacity from 5 - 9

Figures 5.6 and 5.7 show that both SAMs and AAMs were more plentiful in the end of the RASM runs than they were in BFORM. RSRG/SOS rendered the most optimistic assessment of weapon capacity. Without possessing more information on the structure of the programming, the rate of missiles are transfer, or the number of replenishments that occurred, it is impossible to determine why

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RSRG/SOS results were so much different from the other models. RASM, in the Delivery Boy mode, also varied significantly from the other cases. This is caused by the difference in the number of replenishments completed over the thirteen day run. The difference is not nearly as great with regard to the AAMs since they are easier to transfer and are only being delivered to the three aircraft carriers.
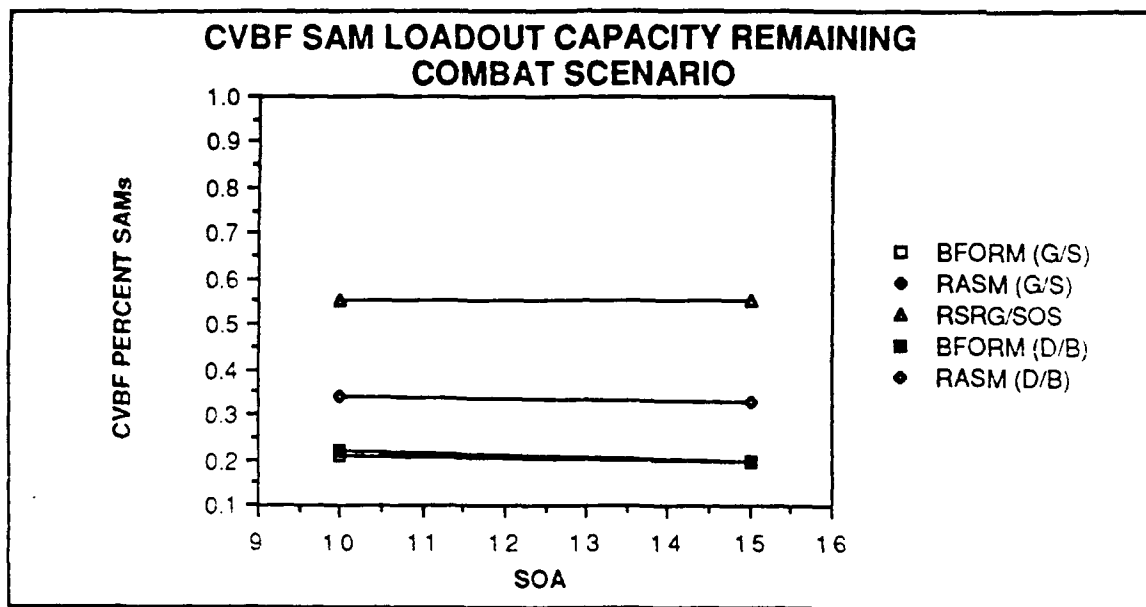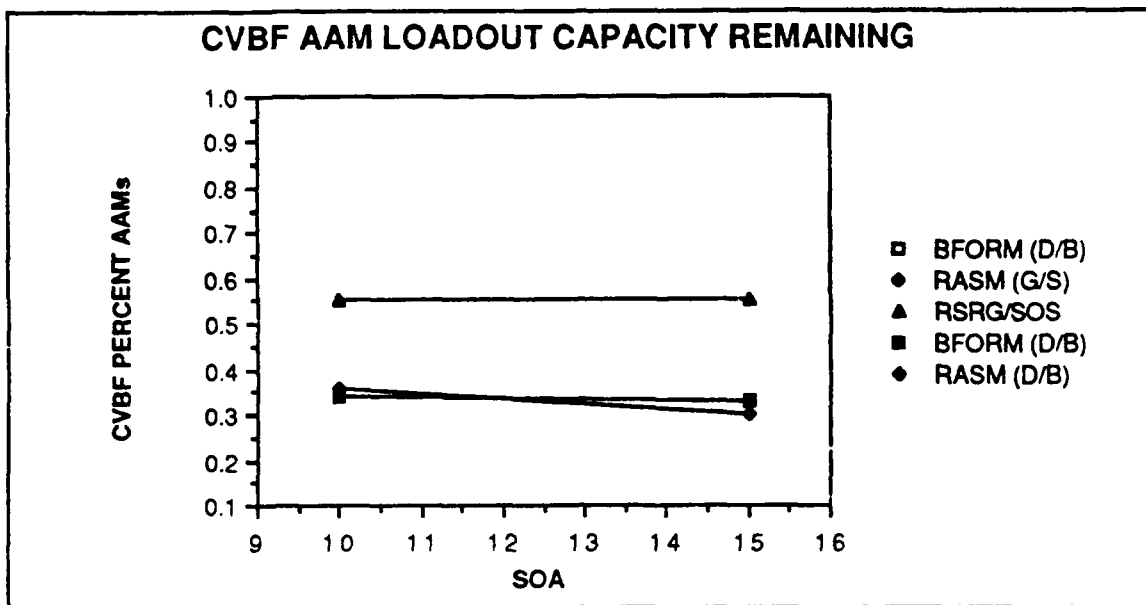

Figure 5.6 SAM Capacity from Cases 5 - 9

CVBF AAM LOADOUT CAPACITY REMAINING

Figure 5.7AAM Capacity from Cases 5 - 9

By using an expected rate of consumption of 605 kgallons per day when CVBF SOA is 10 knots and 869 at 15 knots, the total days of sustainability in fuel was estimated in figures 5.8 and 5.9. These figures show a considerable decline as speed increases. The days of sustainability will depend on the type of underway replenishment policy that is being employed and, to a less significant extent, the type of model used. In the both cases, BFORM results in remaining number of days of sustainability is less than the other two models.
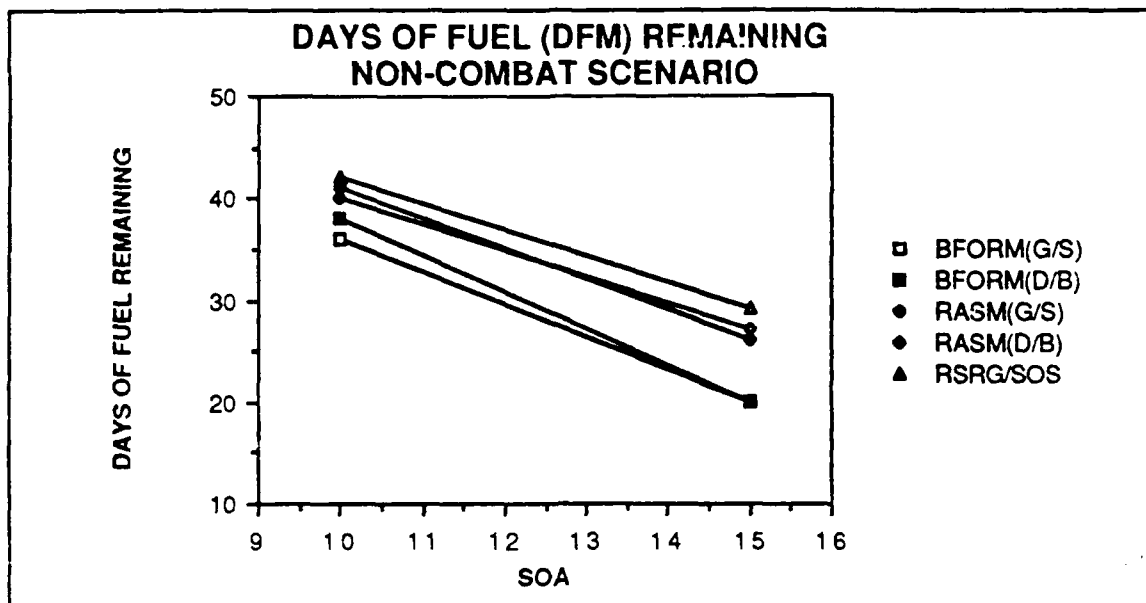
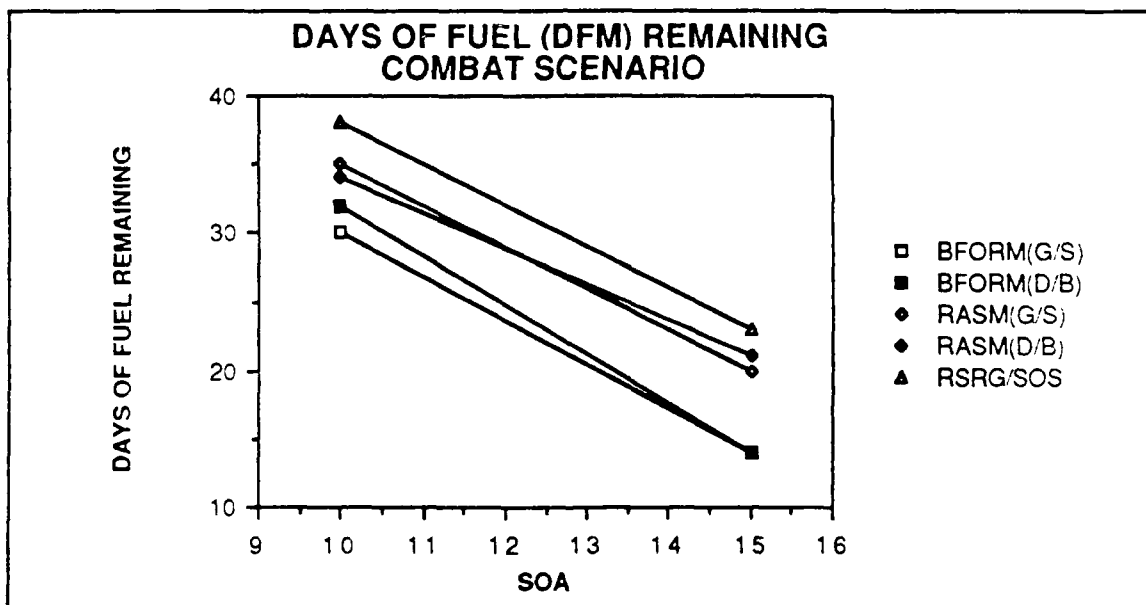**Figure 5.8 DFM Capacity from Cases 1 - 4**

Figure 5.9 DFM Capacity from Cases 5 - 9

In Figure 5.9, the combat scenario, the two models render similar answers by mode of unrep: however, BFORM results are still slightly lower. There are two possible reasons for this apparent difference in the models output. The first is the difference in how the models calculate fuel consumption. The second reason is related to the number of underway replenishments that transpire during the run.

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As mentioned earlier, RASM estimates a higher number of completed replenishments during a run than BFORM. In the combat phase, unrealistically RASM allows for underway replenishment to be completed during AAW action or strikes. BFORM stops transfer activity at the point where weapon expenditure begins.

Another important MOE is the amount of time consumed by screen ships and other combatants for in replenishment evolutions. BFORM and RASM keep track of the amount of time spent off station by combatants. The average amount of time spent off station by a combatant was higher and more consistent in BFORM than it was in RASM. Figures 5.10 and 5.11 show that BFORM estimated a slightly higher amount of time than RASM spent off station by combatants as speed increased, holding replenishment modes constant. RSRG/SOS does not provide any output to be used in this comparison. In the NON-COMBAT SCENARIO (Figure 5.10), BFORM and RASM cross in their calculation of time off station using the Gas(Service) Station method (G/S). The cause for RASM's decrease in time off station as SOA increases is unknown to this author, since the information relating to the individual time for each ship is not available from the model's output.
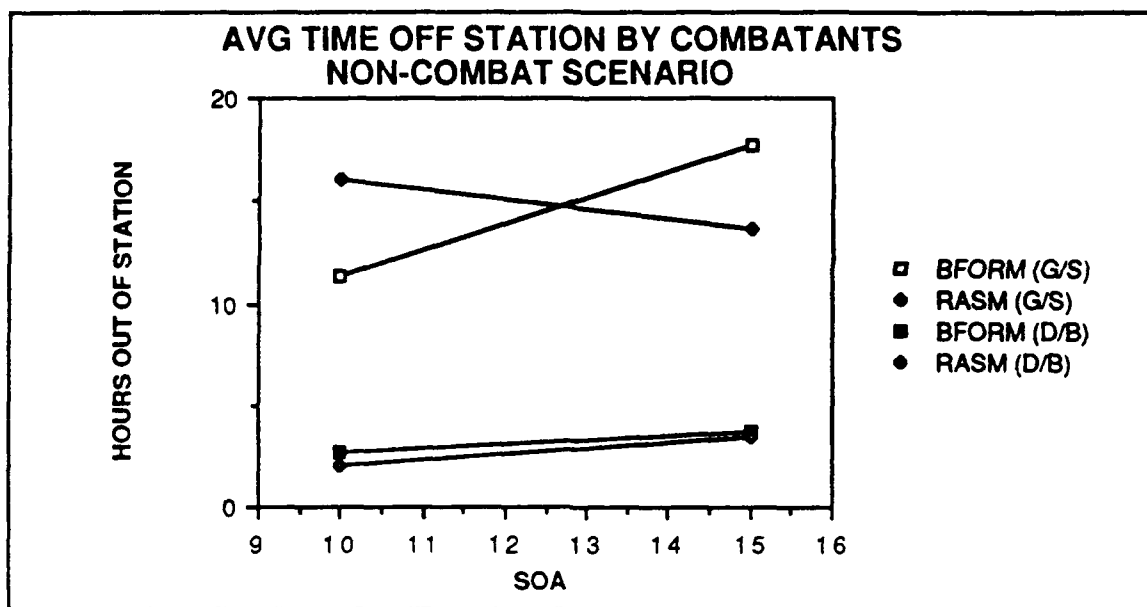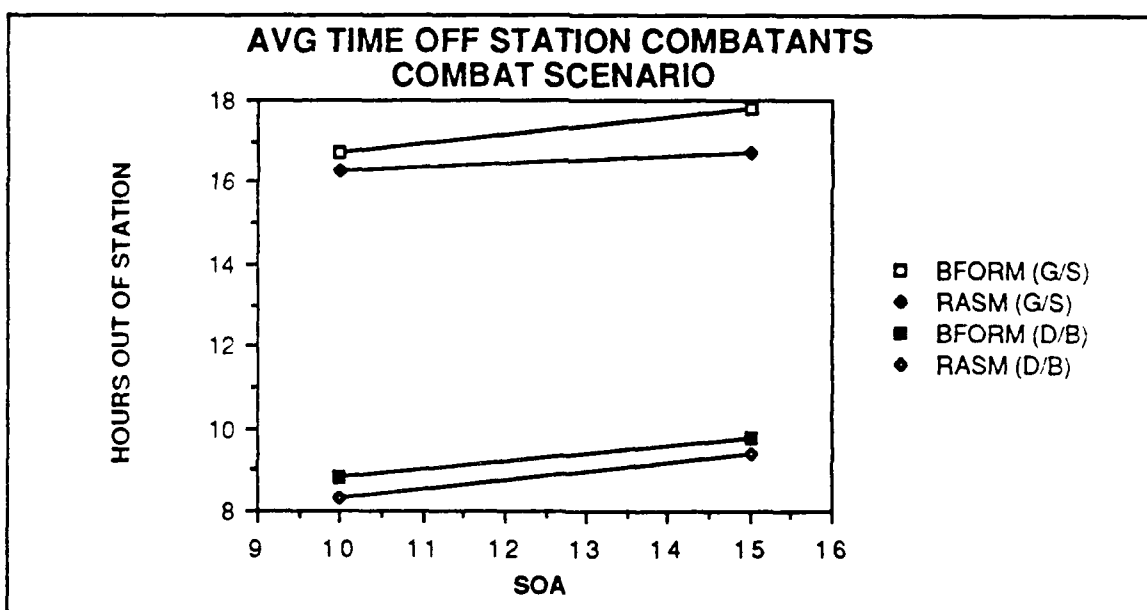
Figure 5.10 TIME OFF STATION from Cases 1 - 4

Figure 5.11 TIME OFF STATION from Cases 5 - 9

The average number of unreps completed per combatant during the thirteen day scenario, Figure 5.12 and Figure 5.13 , indicate that the difference in fuel available and days of sustainability may be due to a greater number of unreps being completed in the RASM runs. This is especially true in the high SOA runs.
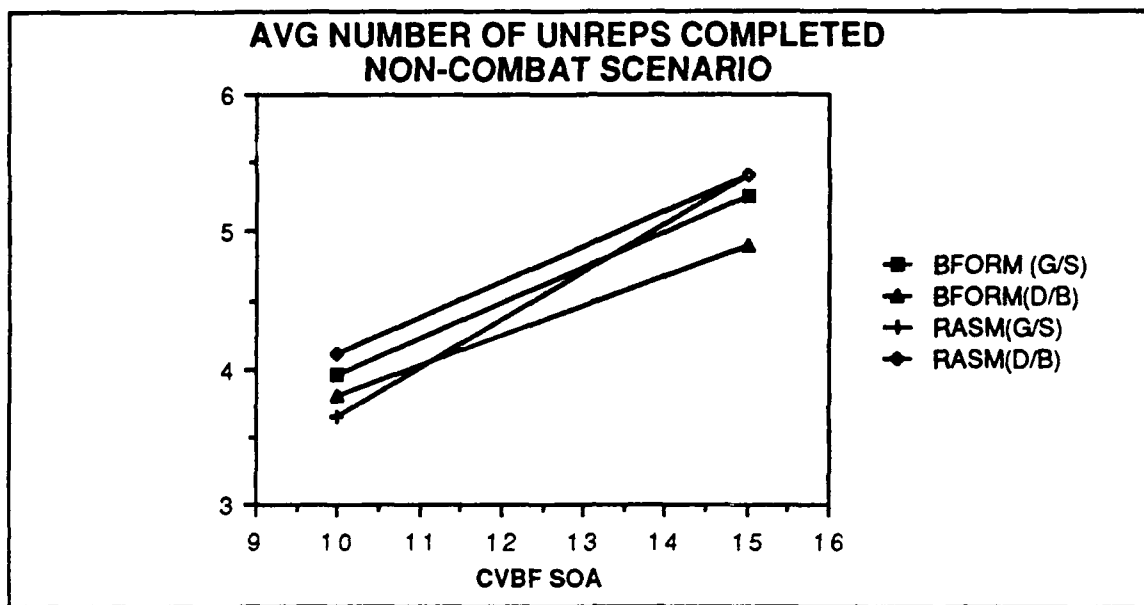
AVG NUMBER OF UNREPS COMPLETED
NON-COMBAT SCENARIO

- BFORM (G/S)
- BFORM(D/B)
- RASM(G/S)
- RASM(D/B)

CVBF SOA

Figure 5.12 Number of Unreps from Cases 5 - 9

AVG NUMBER OF UNREPS COMPLETED
COMBAT SCENARIO

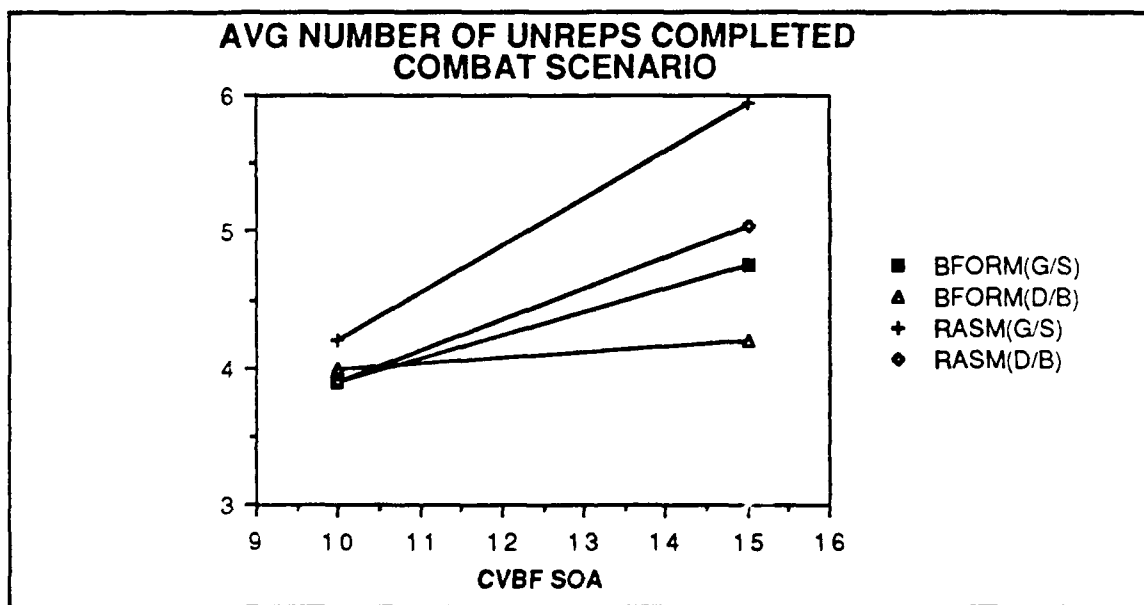■ BFORM(G/S)
▲ BFORM(D/B)
+ RASM(G/S)
◆ RASM(D/B)

CVBF SOA

Figure 5.13 Number of Unreps from Cases 5 - 9

Results taken from BFORM and RASM may also indicate an upper limit on the SOA and /or the spread of the battle group. For a given number of station ships and combatants, these models can aid greatly in analysis of how these factors affect the battle group's endurance. Figures 5.14 and 5.15 display results of model runs in

the combat scenario when the formation was spread from 100 nm to 125 nm. In all cases, the ending inventory level of fuel decreased as the formation size grew.
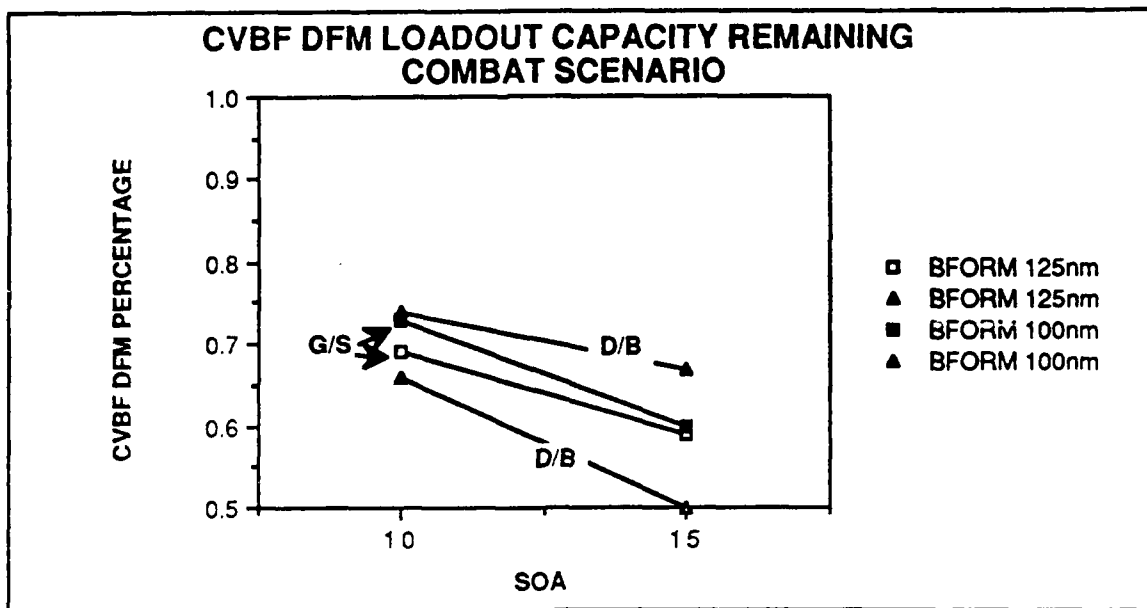

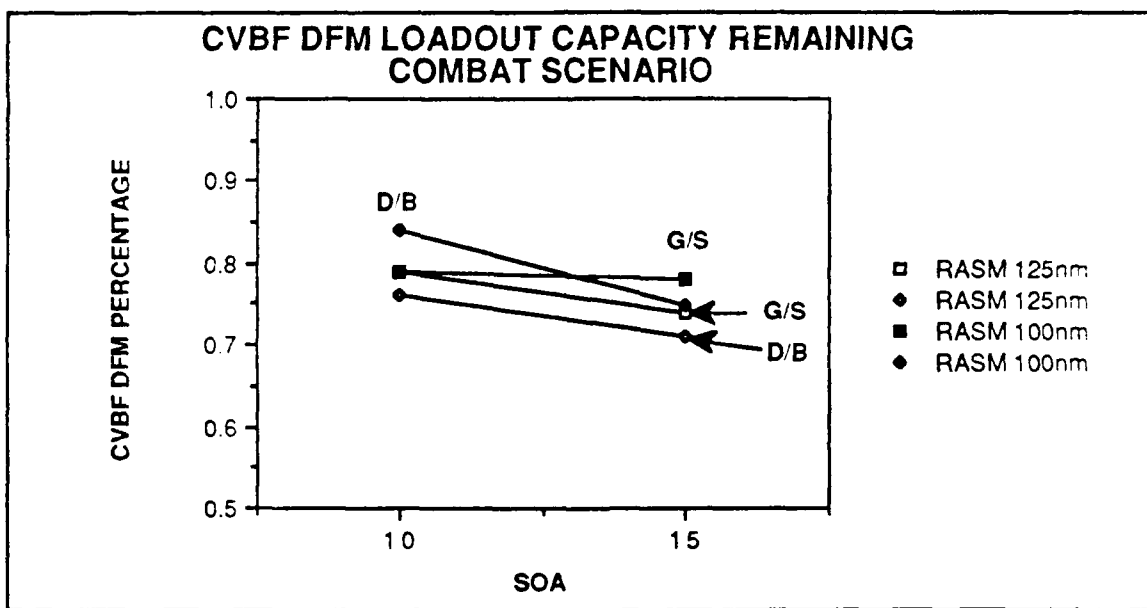Figure 5.14 DFM Capacity from Cases 5 - 12(BFORM)

Figure 5.15 DFM Capacity from Cases 5 - 12 (RASM)

Ammunition levels may be the most critical of all the commodities being replenished. Figures 5.16 and 5.17 show a notable decrease in the number of

weapons available in the battle group as the formation became more dispersed. The results seen were relatively insensitive to replenishment mode.

MINIMUM PERCENT OF SAMs ON ANY COMBATANT COMBAT SCENARIO

Legend:
- □ BFORM 125nm
- ◆ BFORM 125nm
- ■ BFORM 100nm
- ◆ BFORM 100nm
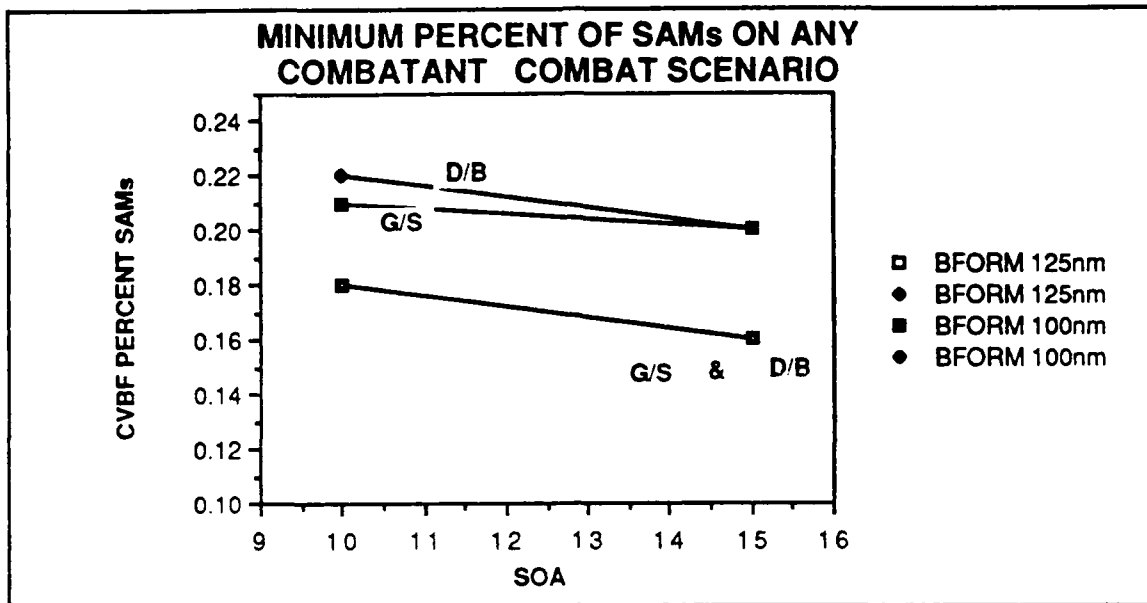
Figure 5.16 SAM MINIMUM Capacity from Cases 5 - 12(BFORM)

MINIMUM PERCENT SAMs on ANY COMBATANT COMBAT SCENARIO

Legend:
- □ RASM 125nm
- ◆ RASM 125nm
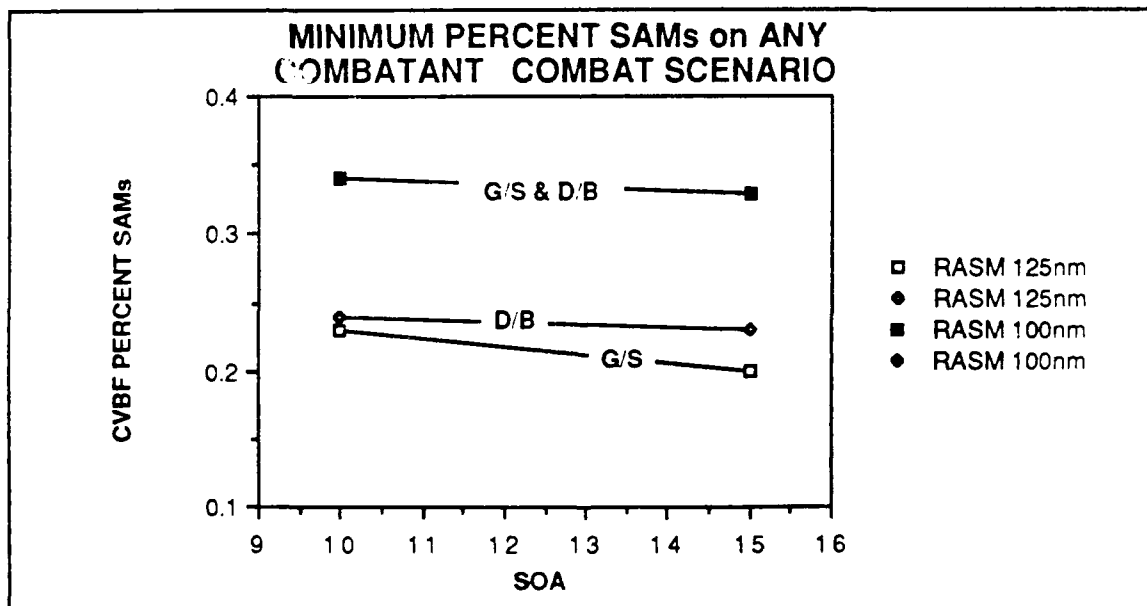- ■ RASM 100nm
- ◆ RASM 100nm

Figure 5.17 SAM MINIMUM Capacity from Cases 5 - 12(RASM)

Figures 5.18 and 5.19 show how the average time off station increased as the ships spread out from the formation center.
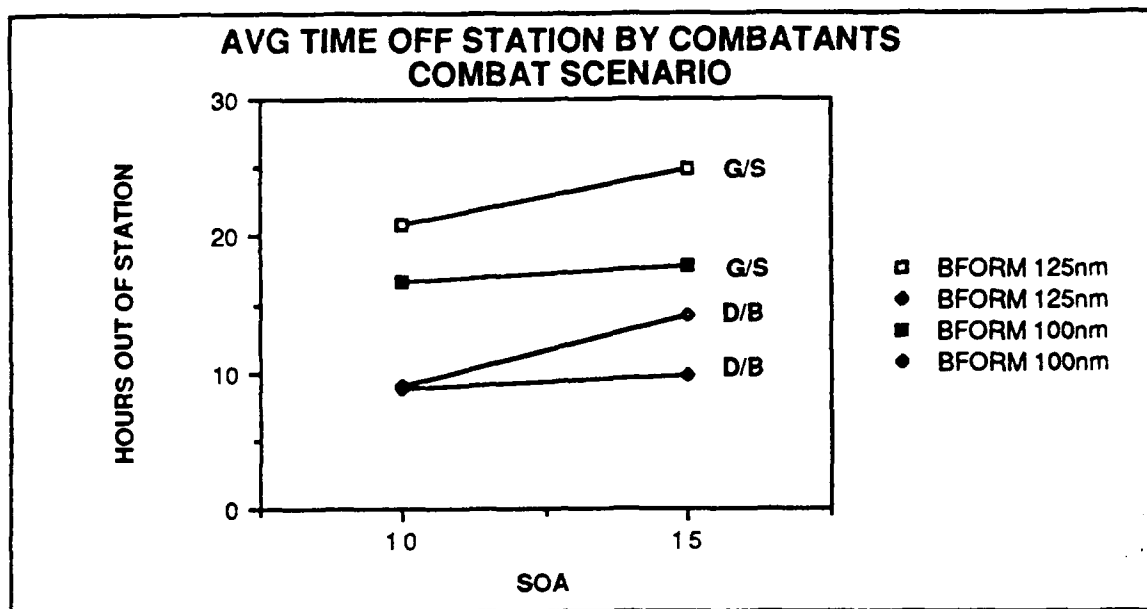
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AVG TIME OFF STATION BY COMBATANTS
COMBAT SCENARIO

HOURS OUT OF STATION

G/S
G/S
D/B
D/B

□ BFORM 125nm
◆ BFORM 125nm
■ BFORM 100nm
● BFORM 100nm

SOA

Figure 5.18 TIME OFF Station from Cases 5 - 12 (BFORM)

AVG TIME OFF STATION BY COMBATANTS
COMBAT SCENARIO

HOURS OUT OF STATION

G/S
G/S
D/B
D/B

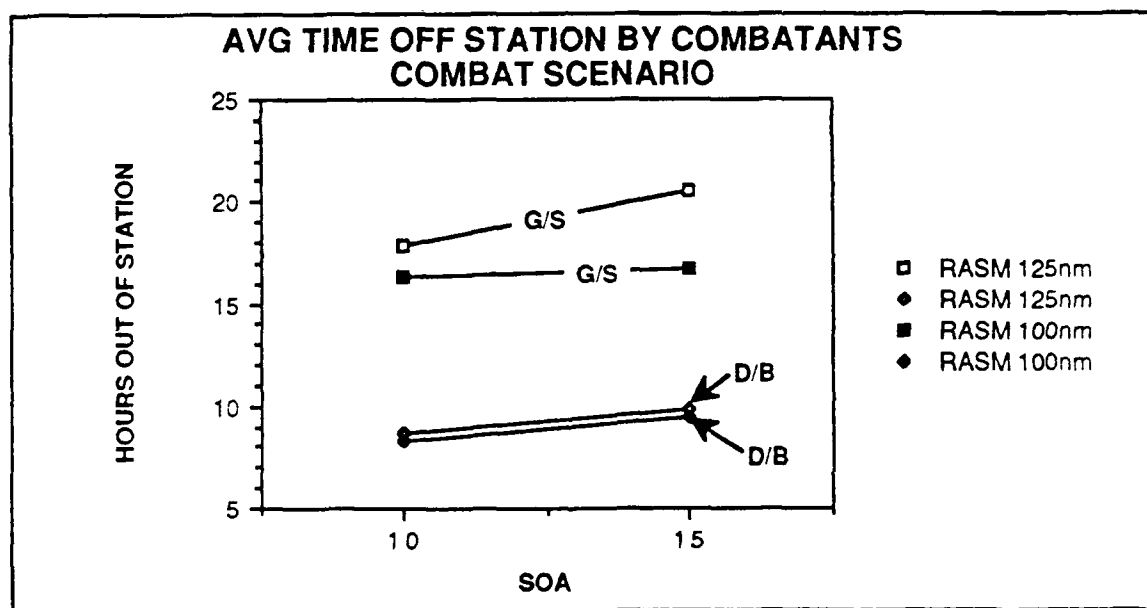□ RASM 125nm
◆ RASM 125nm
■ RASM 100nm
◆ RASM 100nm

SOA

Figure 5.19 TIME OFF Station from Cases 5 - 12 (RASM)

The minimum level of commodities on any battle group ship displayed the most dramatic change as battle group dispersion grew. As Figures 5.20 - 5.23 indicate, the minimums for the 125 nm case was less than half the 100 nm case when the SOA was 15 knots. In both BFORM and RASM the CLF station ship was not able to meet all of its replenishment requirements during the run and left many ships low on fuel

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and ordnance. Further analysis of the effect of dispersion and SOA on the CVBF
was conducted by Lt. S. Barnaby in his September 1988 thesis [Ref. 10:p .30].

MINIMUM PERCENT JP-5 LOADOUT FOR ANY
CARRIER   NON-COMBAT SCENARIO

□ BFORM (G/S)
♦ RASM (G/S)
■ BFORM (D/B)
♦ RASM (D/B)
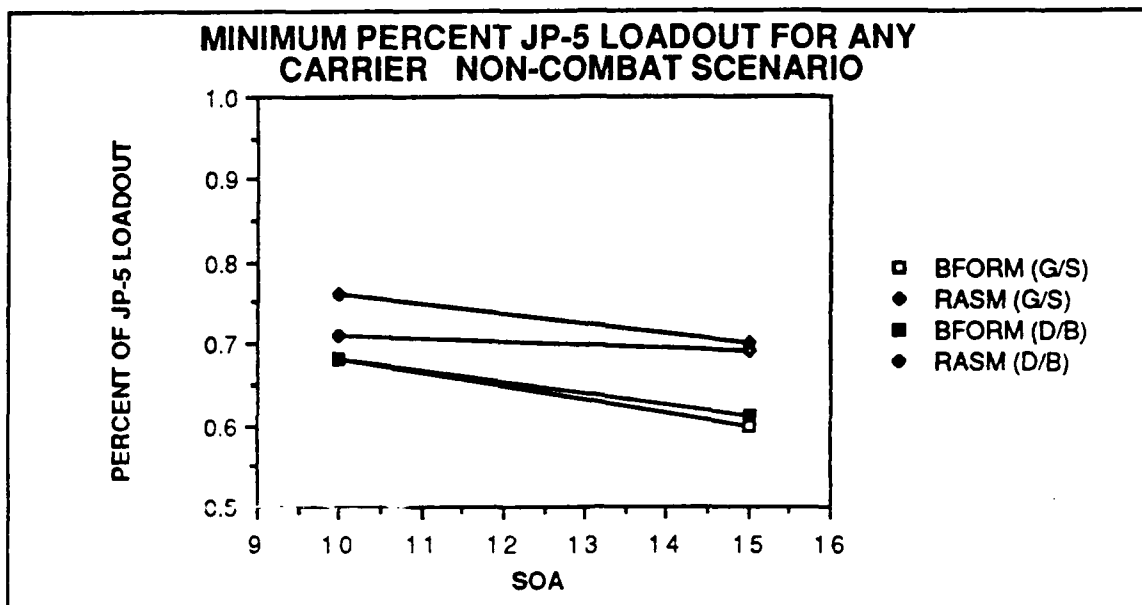
Figure 5.20 JP-5 MINIMUM Capacity from Cases 1 - 4

MINIMUM PERCENT JP-5 REMAINING ON ANY
CARRIER   COMBAT SCENARIO

□ BFORM (G/S)
♦ RASM (G/S)
■ BFORM (D/B)
♦ RASM (D/B)
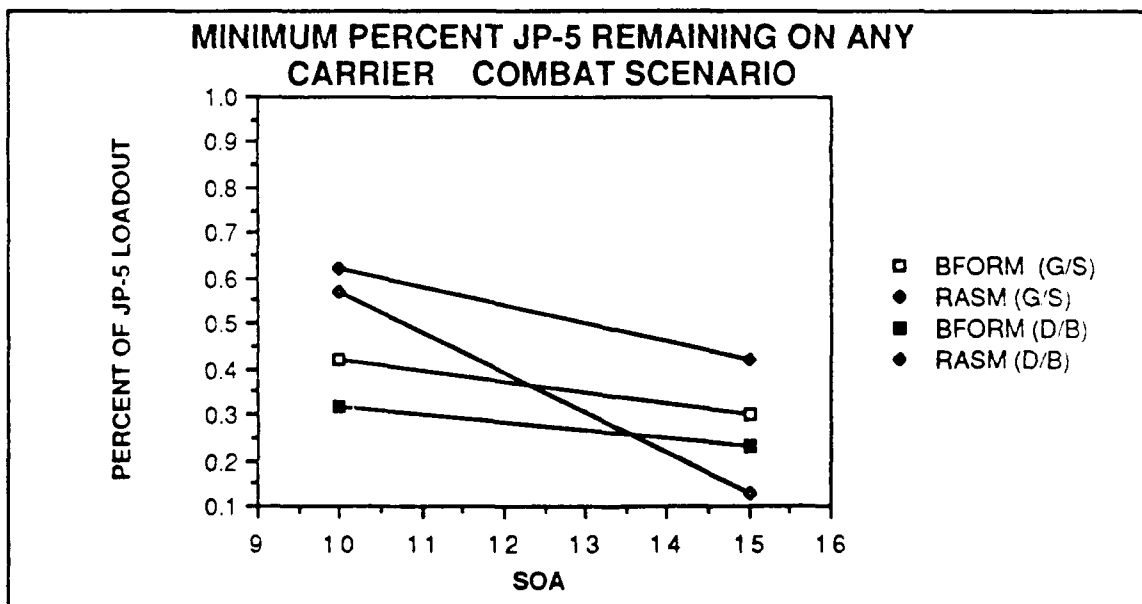
Figure 5.21 JP-5 MINIMUM Capacity from Cases 5 - 9

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MINIMUM PERCENT DFM REMAINING FOR ANY COMBATANT NON-COMBAT SCENARIO

□ BFORM (G/S)
◆ RASM (G/S)
■ BFORM (D/B)
◆ RASM (D/B)
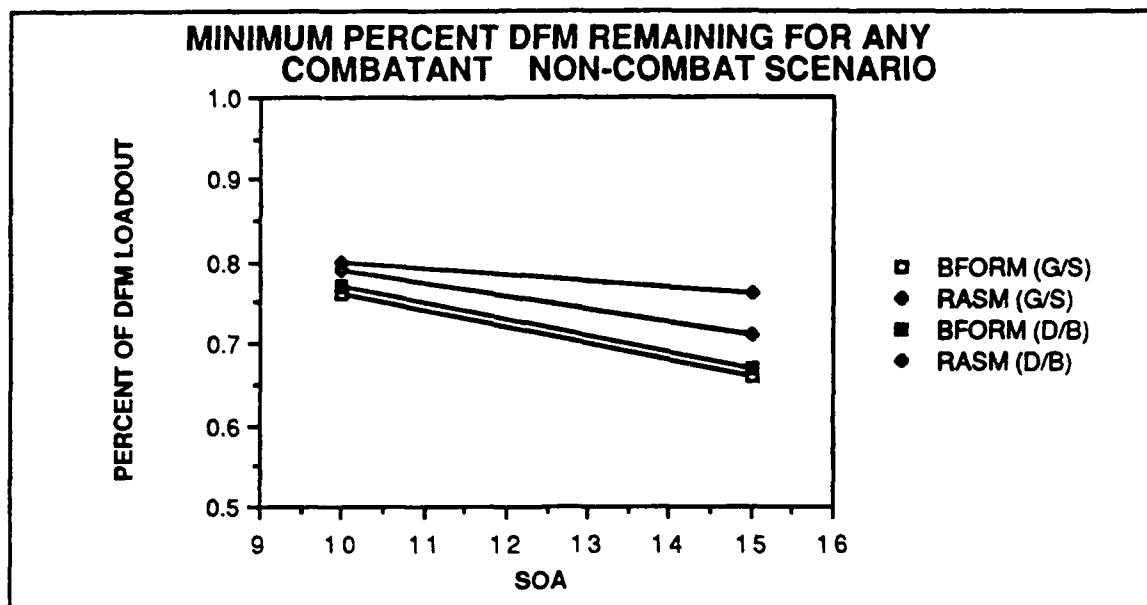
Figure 5.22 DFM MINIMUM CAPACITY CASES 1 - 4

MINIMUM PERCENT DFM REMAINING ON ANY COMBATANT COMBAT SCENARIO

□ BFORM (G/S)
◆ RASM (G/S)
■ BFORM (D/B)
◆ RASM (D/B)
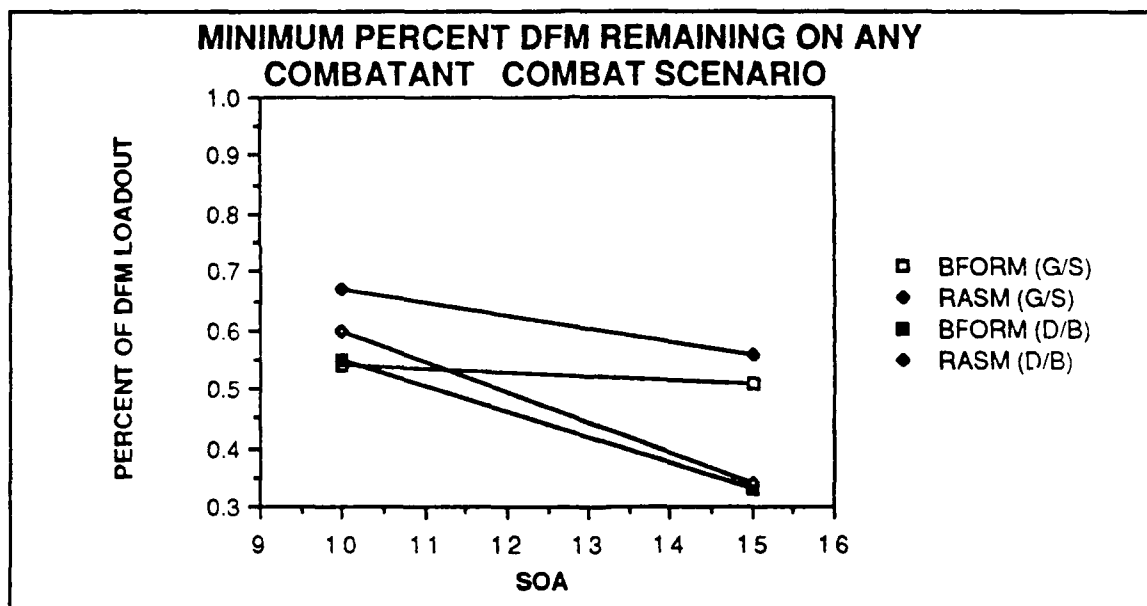
Figure 5.23 DFM MINIMUM Capacity from Cases 5 - 9

The models BFORM and RASM, while cumbersome in their output format, are useful in examining a range of MOEs. RSRG/SOS has merit in its use as a tool for measuring theater level support in the aggregate for battle group operations, but it is not really comparable to the other two models. RSRG/SOS's aggregated output and lack of sensitivity to battle group dynamics such as speed, dispersion, etc.,

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detract from the model's ability to aid the analyst in evaluating battle group endurance and sustainability. All of the models have proven to possess strengths as well as weaknesses in their application and usefulness to an analyst. These will be discussed in the concluding chapter of this thesis.

VI. CONCLUSIONS

A. MODEL STRENGTHS

A comparison of model results is not sufficient by itself in evaluating BFORM, RASM or RSRG/SOS. Much of the difference in the models comes from the flexibility of model input and variety of model outputs that are available for user manipulation and use.

• BFORM provides the user with the greatest of flexibility in range of inputs that can be selected. As was seen in chapter two, many of the intricacies of the replenishment process are available for user definition. The Scheduler algorithm, though not designed to optimize AOE routing, does a reasonable job in planning the replenishment schedule over the course of the operation. Events are positively controlled, allowing an analyst to vary many parameters and examine a substantial number of scenarios. Also, since BFORM is a PC based, menu driven program, it requires little computer knowledge to operate. As a standard output, BFORM provides the user with the minimum level for each commodity for any ship during the simulation run. This type of estimate would prove very valuable to the CVBF operational planner if mission logistical feasibility is in question. For example, in the first four cases, the minimum level of JP-5 and DFM was fairly insensitive to increases in CVBF SOA. In these cases, minimum refers to the lowest level to which a commodity will go during the runs Figure 6.1 below points out, however, that the DFM level was significantly different in the combat scenario when the unrep mode was not of the delivery boy type. Minimum DFM level in this case is the lowest percent of DFM reached by any combatant during the course of the run. Moreover, if a higher SOA is selected and used in the test formation, ships in the formation will run out of fuel. The purpose of this thesis was to explore model

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similarities and differences, so these kinds of stressing cases were not displayed in the results. However, exploratory runs showed the infeasibility of high speeds and dispersed formations taken jointly. More information on this topic was investigated in Lt. S. Barnaby's 1988 thesis [Ref. 10:p. 37].
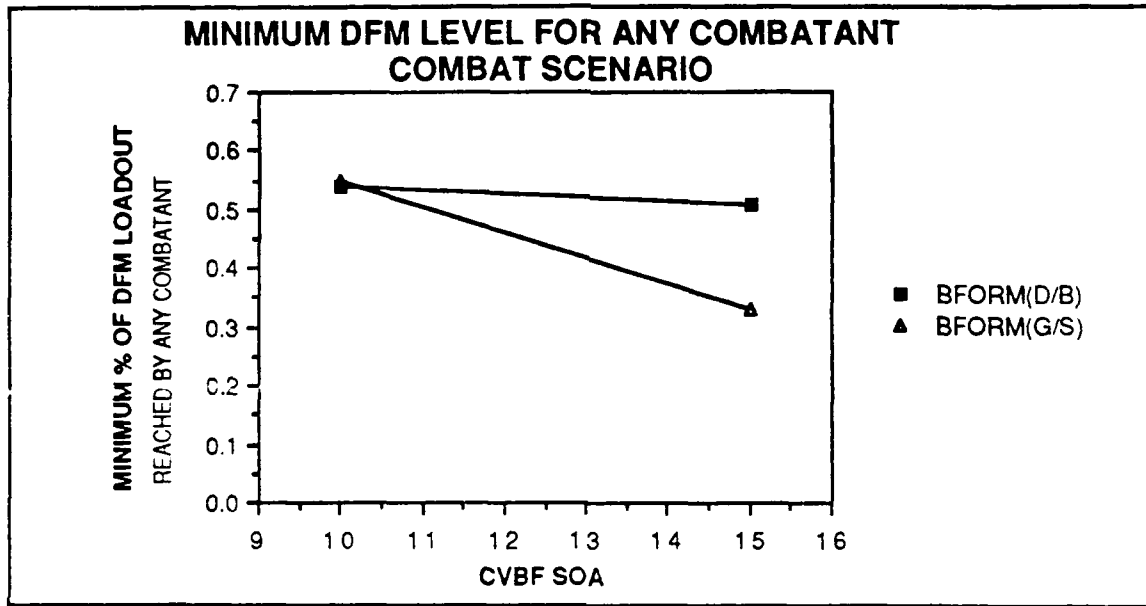

Figure 6.1 DFM MINIMUM Capacity Results from Cases 5-9

• RASM has many features that are similar to BFORM, and provides the user with a faster, more versatile computer model for looking at CVBF logistics. Since it currently is only available for small mainframes and mini computers, it has no real constraint on the size of the battle force or number of events. RASM predicts the required delivery date and amount of commodity needed for shuttle ships to deliver for the user. RASM also provides a break-down of the commodity levels for each ship in both the amount available for transfer and the amount available for that particular ship's use.

• Finally, though RSRG/SOS is by far the most inflexible of the models, however, the amount of input is so limited, it has also proven to be the easiest to operate. Similar to BFORM, it has a PC based, menu driven program. RSRG/SOS

is the only one of the models examined that provides graphical output as its standard output. This is a great advantage. An example from case 5 is presented in Figure 6.2 below, which displays the percent DFM level .
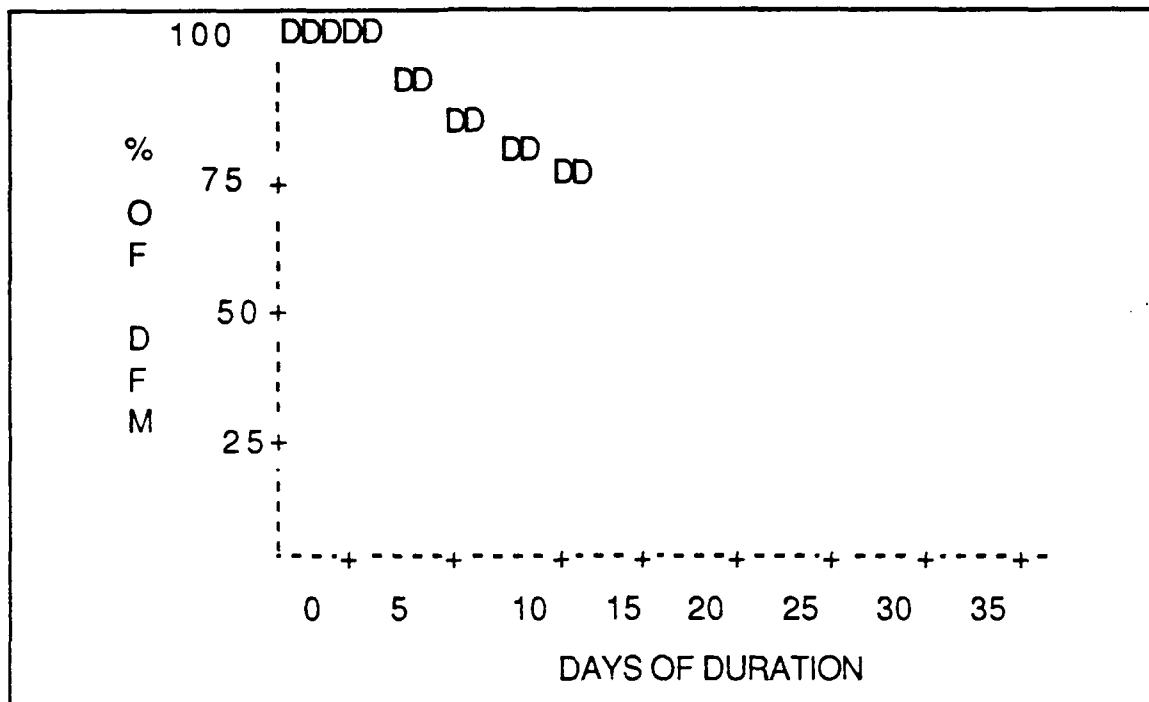
```
  100   DDDDD
         :
         :       DD
  %      :        DD
         :          DD  DD
   75  + :             DD
  O      :
  F      :
         :
   50  + :
  D      :
  F      :
  M      :
   25  +:
         :
         :
         :
         :- --+ ----+ ----+- --+----+ ---+ ---+- ---+-
         0    5    10   15   20   25   30   35
                    DAYS OF DURATION
```

Figure 6.2 SAMPLE OF RSRG/SOS Graphical Output

B. MODEL WEAKNESSES

The major disappointment in all three computer models examined is in the type and quantity of information available from their output. All of the figures in Chapters 5 and 6, except for Figure 6.2 from RSRG/SOS, had to be developed outside of the program and required manual compilation in order for the user to make an assessment. With regard to inventory, the final inventory onboard the CVBF ships is presented, but not the CVBF sustainability that it represents. Difficulty in interpreting results limits these models immediate usefulness to the fleet logistician or tactician.

Another weakness common to the three models is that attrition of either combatant or CLF forces as an event during a run is not provided. This could underestimate the amount and type of CLF assets that are needed to conduct an operation. Attrition can only be investigated by running the scenario in several iterations decreasing the number of CLF ships available between runs. This would be quite bothersome if there was much attrition expected in the mission.

Another common weakness of these models is that they do not allow or model vertrep. Vertical replenishment of stores and ammunition using CH-46 helicopters has greatly quickened the fleets' ability to conduct some logistical operations. The effect of future new developments in vertrep operations should be incorporated into future models so that the impact on the battle force can be measured. However, since most ammunition and all fuel is transferred in the alongside method, this is not a major model deficiency.

Both BFORM and RASM predict some very long replenishments. For example, in some cases the models reported unreps that lasted from twelve hours to more than a day! A modification which limits the amount of time spent replenishing on any one day may reduce this problem.

As it is presently configured, BFORM does not have the capacity to handle more than 30 ships nor 177 events. Several scenarios that were developed by this author to test the models could not be used when they failed to run on BFORM during pilot runs. The model designers are aware of this shortcoming and have plans to upgrade the program so that it will be able to accommodate more complexed scenarios. Presently the user can circumvent this constraint by dividing the scenario into an equivalent number of days for separate runs, using the ending values for each set of days as a starting point for the next run. This becomes quite tedious in a complex scenario and is not a satisfactory procedure.

RASM has a near infinite capacity for force size and scenario complexity, but it is not a portable or menu driven system. A working knowledge of SIMSCRIPT is needed to operate RASM and manipulate its many input files. To obtain an estimate on endurance information, such as the minimum level reached by any combatant, the user must search through a multitude of output files.

Changes in a scenario are easily made, but there is no means of error checking during user input. While these problem do not require an expert to run the model, they do hamper its usability for a user unfamiliar with SIMSCRIPT.

RSRG/SOS output has proven to be the most coarse in providing information concerning how logistics will affect the battle force's warfighting capability. It attempts to give the user a gross idea of the sustainability over the course of the scenario. As a compensatory virtue, it is the only model that examines the distance travelled by the battle force and the geographic operational area in order to predict the time of departure from the ALSB for the shuttle ships.

Since RSRG/SOS is an aggregated model, the user cannot see the logistical effect on any particular ship. RSRG/SOS cannot give the CVBF commander any information on how logistics effect the mission performance in terms of time or disposition of battle force units.

In the final analysis BFORM proves to be similar to RASM, but with slightly more conservative results. RSRG/SOS cannot be substituted for the other two models since it focuses on the larger theater asset level problem and yields coarser results due to its rigid structure.

C. MODEL VALIDATION AND APPLICATION

The apparent difference in the models' different results is significant in some areas but not in all. In general, BFORM and RASM agree in their measurement of the logistical supportability of the mission defined to them and tend to corroborate

each other. However, models like these must be compared with fleet operations to determine the validity of the models.

There are three questions that should be raised in the final analysis of the worth of these models:

a) How useful is the model?

b) Who can best use them?

c) What areas need attention in future models?

1. Utility of the Models

What is the context in which the models can be most usefully employed?

These models were designed to capture the most meaningful aspects of battle force operation in a [theoretically] logical fashion. Unfortunately, the reality of battle force operations and of war is not so well organized. Ships are lost for any number of reasons. shuttle ships may take an excessive amount of time in arriving on the scene to replenish the station ships; unrep rigs break, and any number of other phenomena can affect the actual performance of the CLF. Therefore, the predictive power of these models is constrained by the scenario in which they are used. The ability of the user to predict what will happen accurately will determine how well any model can assess the battle force's logistic situation. The user can expect to get no more than a conservative estimate of the battle force logistic capacity when analyzing the feasibility of a mission. BFORM provided the most conservative estimates of the three models in this analysis. However, any model can provide the user with only a coarse indication of the logistical performance of the battle force operation and highlight areas of concern for logistical planners.

2. Level of Application

At what level are these models most useful in assisting Navy logisticians in evaluating programs, equipment, and / or policies dealing with support of the overall maritime strategy and Battle Force operations?

This type of modeling is beneficial to many levels of naval logisticians. At the battle force commander level, sustainability may be the most important question to be determined. Models such as these provide the user with the ability to explore changes in the circumstances that could face a battle force on a daily basis, and, given a scenario, make an overdone estimate of the altered sustainability of the battle force. Battle force commanders also need to have a good estimate of how replenishments will affect a task group's overall combat effectiveness. In BFORM and RASM, the proxy for measuring the effect of these types of operations is given in terms of combatant time off station. Program analysts must make decisions on the cost effectiveness of new procurement programs to the Navy. Their models do not require the exactness needed by a battle force planner, but similar MOEs can be used to estimate the theoretical difference between competing systems.

3. Improvements

What areas of logistical modeling need the most attention to make these tools more useful?

A most common problem in these models is the way in which they present the information to the user. The battle force commander wants to know the sustainability of the battle group or how replenishment policies will affect battleforce effectiveness. A procurement decision maker may require a sense of whether a new CLF ship design will significantly improve the warfighting capability of the fleet. Finally, in wargaming, campaign analysis and other military exercises, a reasonable estimate of the logistical implications of various courses of

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action could certainly be obtained by the use a model of the logistic support of a battle force.

In conclusion, these types of models will go far toward illuminating logistic concerns in the Navy. Information from a fleet exercises can provide the type of data base which is needed to validate and improve these models.

To date, tactics developed during wargames and exercises have paid limited attention to logistical issues. For example, Ocean Safari 85, a naval exercise conducted off the northern Norwegian Sea by COMSECONDFLT, under guidance from the Supreme Allied Commander, Atlantic, recorded logistic operations in a battle setting. Logistical lessons learned described, " ...*a lack of concern or practice, on the part of the battle force in replenishing ammunition and parts vital to the effort* ... ." [Ref. 9:p. 37] Overall, the logistical problems noted would have "...*seriously affected the ability of the fleet to accomplish its wartime mission*," according to Center For Naval Analyses observers [Ref. 9:p. 38], while other problems would slow the battle forces transition from a peacetime to a wartime mode. Logistic models assist fleet planners in determining feasibility of options or tactics.

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